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THEORY OF ENERGY LOSSES OF HIGH ENERGY PARTICLES.*

BY

L. W. NORDHEIM, Ph.D.,

Duke University.

1. INTRODUCTION.

In discussing the theoretical aspects of the cosmic radiation one has to keep in mind that the application of the concepts of the usual theory in cosmic radiation always means an extrapolation to an energy range quite different from that ordinarily dealt with in atomic physics. It is therefore most important to take stock of the things we do know and of those yet unexplained.

At the present time this distinction is equivalent to the one between effects due to electromagnetic interaction and others (due to nuclear or yet unknown interactions). We can say that we know the results of electromagnetic theory and this means that we are able to make some statements on the behaviour of photons and barytrons though we might expect to find new phenomena connected with these particles. We shall discuss, in detail therefore, the electromagnetic effects and what we can explain with their help in cosmic radiation in order to be able to see more clearly where new things have to be brought in.

The result will be that the electromagnetic phenomena are quite sufficient to explain the major part of all cosmic ray

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phenomena, provided the soft component is identified with electrons and protons, and the hard component with barytrons which are charged particles of intermediate mass (around 200 times the electronic mass). The questions which remain yet unsolved concern the origin of the hard rays which, as we shall discuss in Section 5, must be partly terrestial and partly extra-terrestrial and some of their secondary effects (hard showers, bursts). A suggestive attempt to link up the properties of the barytrons with other known phenomena (nuclear forces) has recently been given by Yukawa and others. As discussed in Section 6, these ideas give hope of explaining the mentioned non-electric effects though no definite predictions can yet be made.

2. SUMMARY OF THE MOST IMPORTANT ELECTROMAGNETIC EFFECTS.

We shall collect here only the most important formulæ and give a short discussion of their validity.[1] As is well known, they fall into two groups. The first order effects are given in Table 1. Most of the symbols are self explanatory.

TABLE I.

Energy loss by ionization

$$-\frac{dE}{dx} = NZ2\pi r_0^2 \frac{e^2}{v^2} mc^2 \log 2mv^2 e^{-v^2/c^2} \xi^2 \frac{\Delta}{Z^2 j^2}$$

$$\to NZ2\pi r_0^2 mc^2 \log \xi^2 \frac{mc^2\Delta}{Z^2 j^2}$$

$$j \sim 13.5 \text{ e.v.} \qquad \xi = \left(1 - \frac{v^2}{c^2}\right)^{-1/2}; \quad r_0 = \frac{e^2}{mc^2}$$

Production of fast Secondaries (relativistic energies)

$$\sigma(\epsilon)d\epsilon = 2\pi r_0^2 \left(1 - \frac{\epsilon}{\epsilon_{\max}}\right) mc^2 \frac{d\epsilon}{\epsilon^2}$$

$$\epsilon_{\max} = E \frac{2mc^2 E}{M^2c^4 + 2mc^2 E}$$

E	10^9	$3\cdot 10^9$	10^{10}	M
$\epsilon_{\max}$	3×10^5 10^8	15×10^5 7×10^8	10^8 5×10^9	$1850m$ $200m$

Compton effect

$$\sigma = \pi r_0^2 \frac{mc^2}{\epsilon}\left(\log \frac{2\epsilon}{mc^2} + \frac{1}{2}\right)$$

[1] For a detailed exposition of the theory of electromagnetic effects compare W. Heitler, "Quantum Theory of Radiation," Oxford, 1936, and L. W. Nordheim, *Ann. Inst. Poincaré*, Paris, 1936.

The energy loss by ionization for a particle with charge $\pm e$ depends practically only on the velocity v. In the given formula Zj means the average ionization potential of an atom with charge Z and Δ the maximum energy of collision secondaries (see below). As well known, this energy loss shows a minimum at a kinetic energy of about double the rest energy and above this a slow logarithmic increase with energy. There is no reason to doubt the increase. The greater part of the ionization can be described as a kind of photoelectric effect due to the field of the passing particle at comparatively large distances. The upper limit of the impact parameters which still contribute is determined by the condition that the Fourier components of the field of the passing particle must still contain the atomic frequencies; otherwise the perturbation of the atom is adiabatic and therefore no quantum jumps are induced. This limit shifts outward with increasing energy owing to the Lorentz contraction of the field and this is the cause for the increase in total ionization. The apparent absence of such an increase constitutes, therefore, a rather strong argument in favor of the new particle with considerable rest mass.

In the formula for the production cross section σ of electron secondaries of kinetic energy ϵ some small terms depending on spin forces have been omitted. With this approximation the formula holds for colliding particles of any mass M, the only difference being that a particle with large mass can only produce electrons of not too high energies (from energy-momentum relations). The accompanying table shows the large difference between protons ($M = 1850m$) and barytrons ($M \sim 200m$). A barytron of 10^{10} e.v. can already give about half of its energy to an electron.

The Compton effect finally shows a cross section inversely proportional to the energy of the quantum and therefore is of no great importance at high energies.

For the radiative processes (second order effects) we give in Table 2 approximate but convenient formulæ which again are valid for particles of any mass. They mean roughly that an electron has an about even chance to produce a quantum of comparable energy ϵ during the traversal of one "unit length" l_0 and, similarly a quantum has in l_0 an about even

TABLE II.

Radiation

$$\sigma(\epsilon)d\epsilon = A\frac{d\epsilon}{\epsilon}$$

Pair production

$$\sigma(\epsilon)d\epsilon = \frac{2}{3}A\frac{dE}{E}$$

$$A = \frac{4Z^2}{137}r_0^2\left(\frac{m}{M}\right)^2\log\left(\frac{M}{m}\right)^2\frac{183}{Z^{1/3}}$$

Unit length $l_0 = \frac{1}{NA}$

Ionization limit $\epsilon_c = \frac{1600mc^2}{Z}\left(\frac{M}{m}\right)^2$

Electrons:

	Pb	Fe	Al	H_2O	Air	
ϵ_c	10^7	3×10^7	6×10^7	1.5×10^8	1.5×10^8	e.v.
l_0	0.5	1.8	8.7	38	3×10^4	cm.

chance to produce an electron-positron pair (E = energy of the primary quantum, ϵ = energy of the electron). These effects lead therefore to a rapid multiplication, accompanied by degradation of energy, of primary electrons or photons, i.e., the formation of showers by cascade, as will be discussed later. This multiplication, however, will continue only as long as the energy of the electrons is larger than the ionization limit ϵ_c where radiative and ionization losses become comparable. Below this limit the radiative effects become unimportant. The table gives the constants ϵ_c and l_0 for various materials. The long range in air compared to all other materials should be noted. It means that the multiplication cannot directly be observed in air in contrast to all dense materials.

The validity of the above formulæ for the radiative effects has often been doubted. It was thought that the resulting low penetrating power for electrons would be incompatible with observation and from this argument a number of suggestions have been made to interpret theoretically such a break down. However, a more thorough analysis of the theoretical procedure leading to the formulæ of Table 2 fails to show any adequate reason why the theory should cease to be valid at high energies. This is most easily seen when deriving the formulæ for the radiative effects by the method of

Williams and v. Weizsaecker in terms of passages at definite distances from a nucleus and a Fourier decomposition of the field of the nucleus at the place of the electron (responsible for the acceleration of the electron and therewith for its radiation).

This analysis shows that the actual effective wave lengths and energies in a suitable Lorentz system are of the order $\hbar/mc$ and mc^2 for which the theory is known to hold well. The only circumstance which possibly might introduce some modification is the fact that at high energies Fourier components of shorter wave length are superposed on the effective ones. The presence of the former would need to reduce therefore the action of the latter in order to produce a break down and hardly any reason can be seen from present developments which would justify such an assumption.

On the other hand, a change in the radiative formulæ would mean that other formulæ which seem to be in agreement with observation would also need to be changed. This is most clearly seen from Table 3 which summarizes the results from

TABLE III.

Effective collision parameters R in units $\lambda\!\!\!^{-} = \frac{\hbar}{mc} = 137 r_0$
Primary ionization $137 < R < \xi(137)^2$
Fast secondary electrons $R \sim \left(\frac{mc^2}{\epsilon}\right)^{1/2}$
Nuclear scattering $\frac{1}{Z} < R < \frac{1}{Z^{1/3}}$
Radiative effects $1 < R < \frac{137}{Z^{1/3}}$

semi-classical analyses of various effects. Any break down of theory can be expected only for near passages of electrons to the electrical fields of nuclei, as only in this case short Fourier components or large field strengths will be involved. It is now seen that both the scattering of the passing particle by a nuclear field and the production of electron secondaries even of energies of order mc^2 involve nearer passages than the radiative effects. One should therefore expect that also these two effects had to be modified in case of a break down. It is interesting to note that the production of medium fast

secondary electrons (of energies $\sim mc^2$) and the nuclear scattering [2] (if the energy is measured through the curvature in a magnetic field) are both practically independent of the mass of the involved particle at relativistic energies. A validity of the formulæ for these effects together with radiation less than computed for electrons suggests, therefore, strongly a particle of higher rest mass, i.e., the barytron. For $M = 200m$ the radiative effects are already negligible for all occuring energies.

As a whole, there are no valid reasons from the theoretical side to doubt the formulæ for the radiative effects. If we can show that they account for a great number of observed effects we can feel doubly certain that they are correct. Of course, the possibility of maintaining the theory rests entirely with the assumption of the barytron nature of the hard component, but it might be said that just the attempts to find experimentally the limits of validity of radiation theory led to the evidence regarding the existence and mass of this new particle.

3. THE ABSORPTION OF THE COSMIC RADIATION.

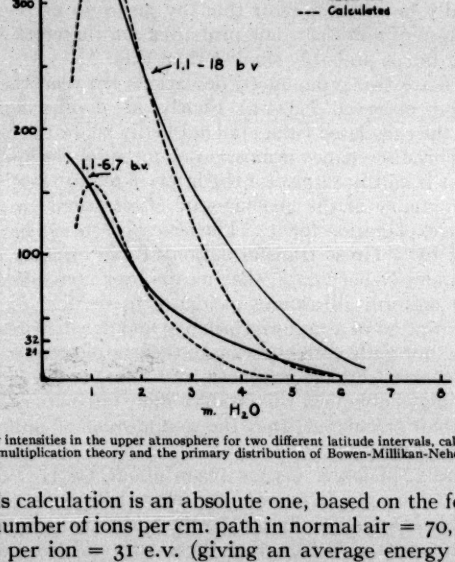
As the first problem with regard to the comparison between theory and experiment we investigate the absorption of cosmic radiation. For the upper atmosphere where the soft component is apparently predominant, the most complete and strictly comparable data have been given by Bowen, Millikan and Neher [3] who have measured the ionization versus depth curves at different latitudes which, according to the theory of the action of the geomagnetic field, correspond roughly to different minimum energies for the incoming cosmic rays. It is then possible to obtain the total energy brought in by the cosmic rays of different energy ranges by measuring the total energy used up for ionization at all depths. Bowen, Millikan and Neher have thus derived from their data the energy distribution of the charged part of the cosmic ray primaries up to about 18×10^9 e.v., which is the minimum energy at the equator from the geomagnetic field (compare also the report of Dr. Johnson to appear in a future issue). We have now taken

[2] Williams, *Phys. Rev.* **53**, 433 (1938) and Kernphysik, edited by E. Bretscher, Zürich (1936).

[3] Bowen, Millikan and Neher, *Phys. Rev.*, **53**, 855 (1938).

this energy distribution and calculated from it the ionization versus depth curves under the assumption that all primaries are electrons obeying fully the radiation theory. Figure 1 shows the results for the latitude intervals Madras (3°)—Saskatoon (60°) and Sam Houston (38°)—Saskatoon (60°) corresponding roughly to the energy ranges of 1.1 to 18 and 1.1 to 6.7 × 10^9 e.v.

FIG. 1.



Cosmic ray intensities in the upper atmosphere for two different latitude intervals, calculated from multiplication theory and the primary distribution of Bowen-Millikan-Neher.

This calculation is an absolute one, based on the following data: number of ions per cm. path in normal air = 70, average energy per ion = 31 e.v. (giving an average energy loss per gram $cm.^{-2}$ air of 1.8 × 10^6 e.v.). This gives for the number of primary rays in the units used by Millikan (number of ion pairs produced per ccm. normal air) according to the foregoing analysis 4 to 5 for $E > 18 \times 10^9$ e.v.; 10 to 11 for 18×10^9 e.v. $> E > 6.7 \times 10^9$ e.v.; and 20 to 22 for $E < 6.7 \times 10^9$ e.v. For the number of electrons produced at various depths the

values given by the author [4] have been used. The agreement with observation is surprisingly good and better than could have been anticipated from the uncertainties of theory and experiment. It shows that the degree of multiplication is exactly the one predicted by theory. The agreement is equally good for both energy ranges which means that a break-down of the theory cannot occur for energies below 18×10^9 e.v. in air. Furthermore, it is evident that there is not much room for primaries other than electrons as their presence would destroy the agreement with the cascade theory. Even with a generous allowance for uncertainties of the assumed figures, they can hardly be more in error than by 30 to 50 per cent, and the fraction of non-electronic primaries can therefore also not be larger but is probably smaller than this.

There are two pronounced deviations between the calculated and observed curves. Firstly at depths less than $1m$ H_2O the calculated values fall markedly below the observed ones. This discrepancy is most pronounced for the low energy range but is hardly extant for the interval 6.7 to 18×10^9 e.v. The asymmetry of the geomagnetic effect seems to give an adequate explanation for it. The observed curves have been obtained by a Gross transformation of the original Bowen, Millikan and Neher [3] data, that means by a conversion of an assumed uniform all around incidence to vertical incidence. The assumption of a uniform primary angular distribution is, of course, not quite correct owing to the complicated nature of the magnetic effects (geomagnetic and solar) and a bundle of rays coming in obliquely will produce more intensity at smaller depths than calculated from the assumption of uniform all around incidence.

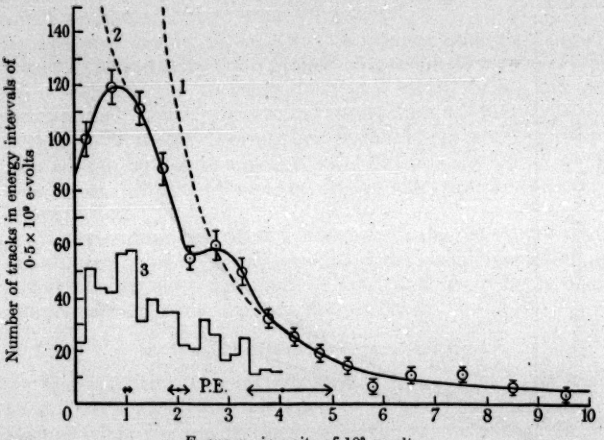
Secondly, at larger depths (from about $3m$ H_2O on) the calculated intensity falls more and more below the observed one. This is undoubtedly due to the additional effect of the hard component. At this stage there exist still two possibilities to interpret this effect. Either the hard rays are of primary nature, in which case the total soft intensity had to be reduced somewhat to make room for some hard rays in the

[4] Nordheim, *Phys. Rev.*, 53, 694 (1938), Table 1. The figures given there have been multiplied by two to include the electrons of an energy below the ionization limit.

upper atmosphere, or the hard rays are secondaries to the soft ones. We shall take up the discussion of this point later on.

For still higher energies (over 18×10^9 e.v., i.e. the field insensitive part of the radiation) a similar comparison cannot be made as we do not know the energy distribution in this region. As shown by the author [4] any absorption curve in the atmosphere can be obtained by a suitable primary distribution, a function $E^{-2.3}$ fitting the data best (E = energy).

FIG. 2.



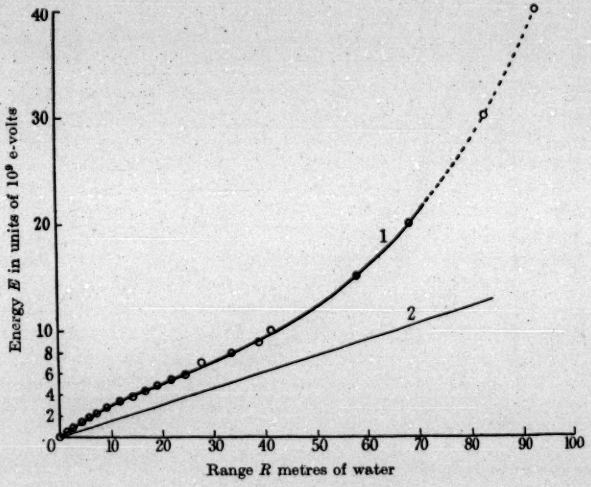
Energy spectrum of positives and negatives together; intervals of 0.5×10^9 *e*-volts Block curve 3 gives same results but for intervals of 0.2×10^9 *e*-volts

We cannot give a similar analysis for the hard component in the upper atmosphere because its intensity at higher altitudes is not known. However, it is possible to follow its history from sea level downward. The energy distribution at sea level has been measured by Blackett [5] and his result is reproduced in Fig. 2.

[5] Blackett, *Proc. Roy. Soc.*, A139, 1, 19 (1937).

It is certain that practically all rays above an energy of some 10^8 e.v. are hard rays. The average energy of this distribution is around 3×10^9 e.v. and above this value the data roughly fit an E^{-2} law which would also give about the right number of rays above 20×10^9 e.v. (upper limit for rays showing a measurable deflection in Blackett's magnetic field). Of course, the actual decrease has to be somewhat steeper than E^{-2} as this would give a divergent total energy.

FIG. 3.



Energy-range relation of cosmic ray particles 1, experimental form of $E = f(R)$; 2, form to be expected assuming only ionization loss

In addition to the energy distribution the absorption of the cosmic radiation underground is known [6] which also is practically due to the hard component alone. One can therefore derive an energy-range relation (under the assumption that such a relation exists). This relation is shown in Fig. 2 (also taken from Blackett [5]).

[6] Compare Wilson, *Phys. Rev.*, **53**, 337 (1938).

The low and high energy tails of this curve (below 3 and above 20×10^9 e.v.) are highly doubtful owing to experimental uncertainties. In the intermediate region the points fall quite well on a straight line, as would be the case, if an energy loss independent of energy is assumed. The slope of this line gives then directly the energy loss. The line 2 in Fig. 3 corresponds to an energy loss of 1.5×10^6 e.v. per gram cm^2. As this figure is rather low and should be $1.8 - 2 \times 10^6$ e.v. instead, we see that the energy loss in the range of 3 to 20×10^9 e.v. can be accounted for completely through the usual ionization, or expressed differently, there cannot be much absorption due to other effects.

The same result can be obtained from an analytical argument. The intensity underground between 20 and 250 m H_2O follows closely the function $d^{-1.8}$ (d = depth below top of atmosphere). Such a law would result from an energy distribution $E^{-2.8}$ if only normal ionization losses are assumed. This is close enough to Blackett's distribution ($E^{-(2+\delta)}$; $\delta < 1$) to warrant the conclusion of the predominance of the stopping by ionization.

Summarizing, we can say with reasonable certainty that the absorption of both components of the cosmic radiation is chiefly due to electromagnetic effects, and that effects of a different nature cannot play a major role.

4. SECONDARY EFFECTS OF COSMIC RADIATION.

The radiative effects (compare Table 2) lead, as well known, to a rapid multiplication of an energetic electron or photon when passing through matter, i.e., the formation of showers. We cannot discuss here the complicated mathematical theory of showers [7] but summarize only some of the results in table 4 which show that the theory is, at least, in good qualitative agreement with observation. The formulæ given are rough approximations only but good enough for this comparison as all experimental results depend much on the geometry of the apparatus used.

The course of a shower is essentially determined by the energy of the entering primary (electron or photon) and the

[7] Carlson and Oppenheimer, *Phys. Rev.*, **51**, 220 (1937). Bhabha and Heitler, *Proc. Roy. Soc.* **A159**, 432 (1937).

TABLE IV.

Characteristics of Showers

Optimal thickness	$\sim l_0\ 1.3 \log \frac{\epsilon_0}{\epsilon_c}$
Half width	$\sim l_0\ \ 2 \log \frac{\epsilon_0}{\epsilon_c}$
Number at optimum	$n \sim \frac{1}{8}\frac{\epsilon_0}{\epsilon_c}$
Fluctuations	$P_n = \frac{1}{\bar{n}}\left(1-\frac{1}{\bar{n}}\right)^{n-1};\quad P_{>n} \sim \left(1-\frac{1}{\bar{n}}\right)^{n-1}$
Energy distribution	$\sim \frac{1}{\epsilon^2}$ for $\epsilon_c < \epsilon \ll \epsilon_0$
	$\sim$ const. for $\epsilon < \epsilon_c$
Angular spread:	
single act	$\theta \sim \frac{mc^2}{\epsilon}$
cascade	$\theta \sim \sqrt{s}\frac{mc^2}{\epsilon}$

$\left(s = \text{number of multiplications} \sim \log \frac{\epsilon_0}{\epsilon}\right)$

thickness of the shower producing layer. The number of photons in a shower is always slightly larger than the number of electrons and positrons. The dotted lines in Fig. 1 can serve as typical examples for theoretical transition curves. The optimal thickness for a shower generating plate depends on the average size of the showers observed (it is to be kept in mind that large showers will be practically always recorded by any apparatus while for small showers the chance of recording depends much on its geometry). For a shower of about 10 rays the optimal thickness in lead is about 1.6 to 2 cm. which is about the usual position of the maxima in the Rossi curves; for bursts of about 1000 rays it is at 4 to 5 cm. of lead, again in rough agreement with observation.

The average energy of the shower particles will be of the order of the ionization limit of the corresponding material (compare Table 2). Consequently, the showers produced in heavy materials (i.e., high atomic numbers Z) will contain a greater number of rays but of lesser energy as compared to lighter materials. This is the cause for the well known transition phenomena, for instance, a thin plate of Pb below Fe increases the size of a shower through further multiplication

while Fe below Pb has the effect of simply absorbing some of the shower rays, i.e., to decrease the size of the shower.

The fluctuations in shower size under otherwise fixed conditions are very large.[8] In Table 4 P_n and $P_{>n}$ give the probability of observing n or more than n rays respectively, if the average number is $\bar{n}$. These fluctuation properties are important for the understanding of the behaviour of bursts as they suggest that in most cases bursts are due to exceptionally large fluctuations. This would explain the exponential dropping off of burst sizes for large bursts while the energy distribution of energetic soft rays is most probably a simple power law of the type E^{-s}, with s between 2 and 3 (from primary distribution and energy distribution in an atmospheric shower itself). Also the very strong increase of burst intensity with altitude is probably a fluctuation phenomenon, i.e., it is determined by the chance of an electron or photon retaining a considerable energy beyond its average range.

The angular spread of the shower particles is mainly determined by their individual energies, i.e., the more energetic rays will show smaller deviations from the original direction. In addition to this, the spread should increase slowly with the size of the shower. This behavior is important for the understanding of the appearance of showers in cloud chamber photographs. The rays showing large deflections, i.e. of small energies, can only come from the lowest layers of the generating material and simulate therefore an origin from a single point, while the more energetic rays of the previous cascade stages are confined to a very narrow cone.

The number of showers below not too thick plates follow roughly the soft intensity in dependence of latitude and altitude, as should be expected. It is important to notice, however, that the actual number of energetic electrons and photons surviving at sea level is very small compared to the total of all rays. An estimate by C. G. and D. D. Montgomery [9] gives for the ratio of the number of showers with more than 10 rays to the number of singles below $\sim$ 1 cm. of lead a value of about 1/1000. As the energy required for such a shower is of the order 2×10^9 e.v. the fraction of electrons of this

[8] Furry, *Phys. Rev.*, **52**, 569 (1937).
[9] Montgomery and Montgomery, *Phys. Rev.*, **48**, 786 (1935); **53**, 955 (1938).

and higher energies can only be of this order of magnitude. Even extrapolating this figure to an energy of about 2×10^8 e.v., with a reasonable energy distribution (E^{-2} to E^{-3}) leads only to a few per cent. This explains the difficulties and partly negative results encountered in the energy loss measurements for electrons as the number of the energetic ones is so small, and shows furthermore that the energy distribution of Blackett (compare Fig. 2) pertains exclusively to the hard component.

The remarks so far made apply only to the showers due to the soft component, i.e., those obtained under thin layers of heavy material. If the radiation theory is at all correct, for which assumption we have found very substantial confirmation, the showers below thick layers of heavy material and underground must be due in the last instance to the hard component. The existence of normal transition effects for these showers [10] demonstrates, on the other hand, their electronic nature, i.e., the hard rays must be able to produce some electron or photon secondaries (it is irrelevant whether these would be produced singly or in multiples as further multiplication will obliterate any such difference).

It seems now that the greater part of these soft secondaries to the hard component can be understood simply as due to direct collisions of barytrons with atomic electrons (for formulæ compare Table 1).

We make the assumption that the maximum energy of the collision secondaries is considerably greater than the ionization limits for all materials in question (this would not be the case for protons as primaries). It follows then from theory that the number and distribution of showers thus produced should be nearly independent of the material (though the rays emerging from heavier materials are less energetic) in agreement with observation. The number of showers will be proportional to the number of secondary electrons of sufficient energy and to the range of the shower. The latter will be proportional to the unit length, i.e., $\sim Z^{-2}$. The former contains firstly a factor Z from the number of atomic (target) electrons. Secondly, to create a shower of a given size the energy of the producing electron has to be a certain multiple of the ioniza-

[10] Morgan and Nielsen, *Phys. Rev.*, **52**, 564 (1937).

tion limit $\epsilon_c \sim 1/Z$. Now the energy distribution of the secondaries of not too high energies is proportional to $d\epsilon/\epsilon^2$ (compare Table 1), the number above ϵ_0 therefore $\sim 1/\epsilon_0$. This gives an additional factor Z making thus the total number of showers independent of the nuclear charge.

To obtain an estimate of the intensity of the soft component generated by and in equilibrium with the hard rays we make use of the fact that the final dissipation of electronic energies is effected by normal ionization, and that the latter is nearly independent of the energy of the electron except near to the end of its range. The equilibrium number of electrons accompanying a hard ray will therefore be very nearly equal to the energy given to electron secondaries per cm. over the ionization loss of an electron per cm. It follows now from the formulæ of Table 1 that the energy given by barytrons of $\sim 10^{10}$ e.v. to electron secondaries of over 10^7 e.v. is about twenty per cent. of the ionization loss of electrons near the minimum. We can compare this estimate with the observation of Nielsen and Morgan [11] who found the percentage of soft rays (of energy above $\sim 5 \times 10$ e.v. necessary to penetrate the walls of the counters used) to be ~ 25 below a layer of rock of $\sim 60m$ water equivalent. At this depth no contribution from the soft primary component can complicate matters, and the average energy of the hard rays is certainly larger than 10^{10} e.v. It seems therefore, that the collision secondaries are sufficient to explain practically all the soft radiation at this location.

A further comparison can be made with cloud chamber statistics. Hopkins (Dissertation, Duke University 1938) found for hard rays (prefiltered by 214 g. cm.$^{-2}$ of lead) emerging from lead a ratio of singles to doubles (one secondary) to small showers (2–4 rays) of 565 : 49 : 6, while a theoretical estimate gives a ratio of approximately 100 : 10 : 1.2 (the number for single secondaries has been calculated as the number of electrons produced with an energy below the ionization limit but emerging with an energy over 10^6 e.v.; the number of showers as the number of electrons of higher energy generated within the optimal thickness for shower production).

[11] Nielsen and Morgan, *Phys. Rev.*, **53**, 915 (1938).

As the result of all these considerations we find again that the electromagnetic effects are sufficient to explain the major part of the secondary phenomena. It is, however, doubtful whether the suggested mechanisms are sufficient to explain all bursts especially those produced in light materials. It seems that the number of bursts generated in comparatively thin layers of light materials is too large to be accounted for by the cascade theory since the number of bursts of given size near the maxima of the transition curve is about the same below iron and lead in contradiction to the cascade theory.[12] Also it is still an open question whether bursts occur below layers too thin to produce an effective multiplication. If this were true, explosion processes instead of multiplication had to be assumed. It is also doubtful whether the number of very energetic collision secondaries is sufficient to explain the observed frequencies of large showers and bursts below thick layers of material.

Finally the existing evidence for a hard secondary radiation (of a range of about 200 gram per cm.$^{-2}$) as the second maximum of the Rossi curves and the so-called hard showers [13] indicate processes of other than electromagnetic nature. The possible contribution of these effects to the total ionization and absorption seems, however, to be quite small. We shall discuss the question of a possible mechanism for these effects in Section 6.

5. REMARKS ON THE ORIGIN OF THE HARD COMPONENT.

The principal problem which yet remains unsolved is the question of the origin of the hard component. Though it cannot yet be decided definitely owing to the lack of sufficient data regarding the distribution of the hard component at higher altitudes and different latitudes (so far we could trace the history of the hard rays only from sea level downwards) some important conclusions can already be drawn.

It can firstly be shown that the major part of the not too energetic hard rays must be produced within the atmosphere itself. This is most easily seen from a comparison of their energy distribution (compare Fig. 1) with the geomagnetic

[12] Euler, *Physik. Ztschr.*, 23, 942 (1937).
[13] Compare the report of Dr. Nielsen in this issue.

effect (compare reference 4). The measurements of Blackett were taken at 50° latitude (which is near the knee of the geomagnetic effect where the minimum energy is about 3×10^9 e.v.). If now the hard rays all came from outside the rays of low energy (below $\sim 15 \times 10^9$ e.v. which is equal to the threshold energy at the equator of about 18×10^9 e.v. minus the energy lost in the atmosphere by ionization of about 3×10^9 e.v.) would be cut out at the equator which would give an enormous geomagnetic effect for the hard rays of the order of 90 per cent. instead of the observed 10 to 15 per cent. The assumption of a higher individual energy loss on the other hand would be in contradiction to the penetrating power of the rays from sea level downwards and to the fact that the geomagnetic effect persists up to about 50° altitude which means that some rays of about 3×10^9 e.v. must already be able, with some probability, to penetrate through the atmosphere. The conclusion of the largely atmospheric origin of the hard rays seems therefore to be inevitable.

It is not yet possible to decide whether the primaries to these hard secondaries are themselves of hard or soft nature. A strong point in favor of the latter hypothesis is the fact that according to the analysis of Section 3 there is not much room for a large number of hard primaries entering the atmosphere.

On the present evidence it seems, however, that the hard rays of highest energy (over 15 to 20 $\times 10^9$ e.v.) cannot be secondaries of the soft component but must come from outside. To show this we firstly estimate the production cross section necessary for such an assumption. The number of primaries at the equator (energy over $\sim 18 \times 10^9$ e.v.) was of the order 4 to 5; and this estimate should be rather reliable as it was obtained from two different sources; namely, the total energy measurements by Bowen, Millikan and Neher [8] and the multiplication theory. At sea level the intensity is about 10 to 11 of which 7 to 8 are hard rays. As a further point of comparison we take the data of Morgan and Nielsen [11] at ~ 70 *m.* water equivalent below the top of the atmosphere. At this depth the energy lost by normal ionization alone amounts to 15 to 20 $\times 10^9$ e.v. As the rays must have retained an average energy comparable to the amount lost (the

radiation being hardened when going to larger depths) they can only have been produced by primaries of well over 20×10^9 e.v. so that we are on the safe side.[14] The intensity at this location is 1/20 of the one at sea level which means, in the above units, that there are about 0.4 hard rays; i.e. $\sim$ 1/12 of the total number of rays at the top of the atmosphere. If this fraction were now generated by soft rays (electrons or more likely photons) this production must have taken place in about one unit length of radiation theory as the average energy is already reduced by a factor of about e (basis of natural logarithms) in this distance and the individual energies of the soft rays will have dropped down too far for further creation of hard rays of such penetrating power. This means that the cross section for the production of hard rays of comparable energy by a soft ray must be of the order 1/12 of the cross section for radiative processes, for instance, pair production by quanta.

If now there exists a mechanism for creation of a hard ray of comparable energy by a soft ray there must then exist also the reverse process, that is, the absorption of the hard ray through conversion into a soft one. This process should have, according to the general postulate of reversibility of elementary processes, a cross section of the same order of magnitude as the production cross section, and should lead therefore to a definite absorption coefficient. With the above data we obtain $k \sim 1/12\, l_0 = 0.002/\text{g. cm.}^{-2}$ ($l_0 = 40$ g./cm.^{2} for air). The actually observed absorption coefficient at sea level is $k = 0.0006$ and below 70 m H_2O $k < 0.0002/\text{g. cm}^{-2}$. This figure gives an upper limit as the effect of normal stopping by ionization is included, and the actual absorption coefficient must therefore be still smaller. The discrepancy is therefore at least a factor 10 which places it outside of the probable limits of error.

The conclusion of a different origin of the hard rays of low and high energies seems therefore difficult to avoid, though, of course, it cannot be decided, whether the two groups are of the same or different physical nature (f.i., protons and bary-

[14] The same data, obtained by Nielsen and Morgan, show that non ionizing links cannot be made responsible for bringing down the cosmic radiation to large depths.

trons) and also whether the low energy group is created by the high energy group or the soft component.

6. NUCLEAR FORCES AND THE THEORY OF THE BARYTRON.

Summarizing our previous discussion we can say that the laws of the electromagnetic field explain the absorption of the soft component from the top of the atmosphere on, the absorption of the hard component from sea level on, and that they also account satisfactorily for the major part of the secondary effects, especially the showers.

The remaining phenomena which must be due to other non electromagnetic causes are the generation of hard rays within the atmosphere, the hard showers and perhaps some of the bursts. A theory for these effects can only be expected on the basis of a better understanding of the physical nature of the barytrons, of which so far only the charge and mass (and the latter not too accurately) are known.

If we now look around for non electromagnetic actions which are known and which might have some bearing on the above questions there remains only one major group of phenomena in atomic physics which might be important; that connected with the nuclear forces.

At first sight there does not seem to be much prospect for progress from their consideration. Nuclear forces act between protons and neutrons, and the number of these particles in the cosmic radiation seems to be rather small, though there are undoubtedly some.

The direct effect of the nuclear forces on the behavior of the fast protons has been investigated by Heisenberg.[15] The range of the nuclear forces is smaller than the actual dimensions of nuclei. Therefore, only actual traversals of nuclei by protons will lead to any interaction and in such encounters a small fraction of the primary energy might be given to some constituents of the nuclei. The result for the primaries is then an energy loss proportional to $(c/v)^2$ and to the mass number of the nuclei, that is an effect very similar to the usual ionization losses. Also the order of magnitude is not much different, the nuclear energy loss being about 1/5 to 1/3 (according to the assumed range of the nuclear forces) of the ionization losses.

[15] Heisenberg, *Sächsische Akad. Wiss. Math. Phys.*, **89**, 369 (1937).

As the nuclear forces are exchange forces, the neutron-proton character of the colliding particle can be changed in such processes and, therefore, under thick layers of materials (about 200 g./cm.^{2}) equal numbers of protons and neutrons should be expected.

The effects for the residual nuclei are more interesting. The average energy transfer will be of the order 10^7 e.v.; i.e., we should expect some nuclear reactions of ordinary type. In some rare cases, however, the energy given off to the nucleus might be considerably higher. A proton of not too high energy, perhaps some 10^8 e.v., has a good chance to get stuck in the nucleus, therewith exciting the latter correspondingly. According to Bohr's conceptions on nuclear structure such a highly excited nucleus will evaporate a number of neutrons and protons with individual energies around 10^7 e.v. and this might be the origin of some of the showers of the second kind in which a number of heavily ionizing tracks are seen to emerge from one point into all directions. It should be mentioned, however, that such nuclear excitations could also be produced by quanta (or perhaps barytrons) of corresponding energy which certainly are much more abundant in the cosmic radiation than slow protons. The apparent strong increase of the showers of the second kind with altitude points also to this mode of their origin.

The direct effects of the nuclear forces are thus without much importance. There is, however, one line of reasoning, due to Yukawa,[16] which leads to a very suggestive though indirect connection between nuclear forces and the hard rays. It is well known that the quantization of the electromagnetic field, i.e., the introduction of photons, is a necessary complement to the quantization of electronic motion. As all material particles are connected with a wave or field phenomenon, so every field of force must also have its corpuscular side. For the electromagnetic field this leads to the conception of light quanta. One can ask, therefore, for the particle features associated with the nuclear force field. Though we do not know too much about the nuclear forces and particularly nothing of their behavior at relativistic velocities of neutrons and protons, some general arguments can be given.

[16] Yukawa, *Proc. Phys. Math. Soc. Japan*, **17**, 48 (1935), **20**, 1 (1938).

In the corpuscle picture the interaction between two particles can be described as due to a "playing ball" effect, that is the emission of a "carrier" by one of the particles and its subsequent reabsorption by the other. In the case of the Coulomb interaction between electrical charges the carriers are of photonic nature (strictly speaking also "longitudinal" photons have to be introduced to derive a static Coulomb field, but we are here not concerned with the details of this theory).

The nuclear force field shows now two characteristic features. Firstly the range of the nuclear forces is finite (in contrast to the slow decrease with distance of the Coulomb field) with a range slightly smaller than the electronic radius $r_0 = e^2/mc^2 = 2.8 \times 10^{-13}$ cm. This finite range suggests a heavy rest mass for the carrier. With a proton and a neutron at rest, no sufficient energy is available for an actual creation of a carrier particle. However, in quantum mechanics even then a virtual existence for it remains possible, the energy necessary for creation, i.e., the rest energy, acting simply as a kind of potential barrier. The probability of finding the carrier at a distance r from the proton will be proportional to $\exp(-r/\lambda)$ ($\lambda = \hbar/\mu c$ = Compton wave length and μ = rest mass of the carrier) and the total interaction potential will be $G/r \exp(-r/\lambda)$, where G is the analogue to the electric charge, the additional exponential factor being due to the mentioned barrier effect. If the range were exactly equal to r_0 one would have $\mu = 137\, m$ (m = electronic mass) but as the range is somewhat less, $\mu = 200\, m$ will fit best. The value of G must then be assumed [17] to give $G^2/\hbar c = 0.29$ for the analogue of the "fine structure constant" in order to obtain the known strength of the nuclear forces.

Secondly the nuclear forces are of exchange character. This implies a transfer of charge between proton and neutron in their interaction which means that the carrier particles must themselves have the charge $\pm e$. The properties of the nuclear force field lead thus quite naturally to the conception of a "barytron." To state the principal idea once more, nuclear particles, protons and neutrons, carry with them a field of forces, similar as charged particles carry an electromagnetic field, and the associated quanta or carrier particles corre-

[17] Sachs and Goeppert-Mayer, *Phys. Rev.*, 53, 991 (1938).

spond just to the picture one has of the hard component of the cosmic radiation.

According to this theory a number of effects for barytrons seem possible.[18] They could be created in collisions of protons and neutrons of sufficient energy according to the scheme

$$\text{I.} \qquad P + N \rightarrow \begin{matrix} N + N + B^+ \\ \searrow \\ P + P + B^- \end{matrix}$$

and also by photons as

$$\text{II.} \qquad h\nu + P \rightleftarrows N + B^+$$

and by multiplication

$$\text{III.} \qquad B^+ + P \rightarrow P \qquad \text{or} \qquad N + \text{several } B.$$

The reverse process to II would provide an absorption mechanism; and also effects of high multiplicity (simultaneous production of several barytrons in one act) could be expected as the value of $G^2/\hbar c$ is so near to unity.

These processes are just the kind required for the "non-electromagnetic effects" mentioned earlier in this paper (generation of hard rays within the atmosphere, hard showers, explosion bursts). Unfortunately the details of this theory are still uncertain and beset with many difficulties. We can, however, show from dimensional arguments that reasonable values for the cross sections of the above processes can be anticipated. For the interaction between a barytron and a proton or neutron we can define a characteristic universal length $R = G^2/\mu c^2 \sim 0.2\, r_0$; and for the interaction between barytrons and the electromagnetic field (photons) a length $\rho = e^2/\mu c^2 \sim 0.005\, r_0$. Then, dimensionally, we would obtain for the process I (analogue to the radiation of electrons)

$$\text{I.} \qquad \sigma_P \sim A(G^2/\hbar c)(G^2/\mu c^2)^2 \sim A \times 0.01\, r_0^2$$

and for II (emission of a barytron by a proton and absorption of $h\nu$ by the barytron, i.e., one electromagnetic and one nuclear interaction)

$$\text{II.} \qquad \sigma_{h\nu} \sim A(e^2/\mu c^2)(G^2/\mu c^2) \sim A \times 10^{-3}\, r_0^2,$$

[18] Nordheim and Nordheim, *Phys. Rev.*, *54*, 254 (1938). Heitler, *Proc. Roy. Soc.* **A** in press.

where A is the atomic weight of the nucleus (the nuclear constituents can be assumed to act independently and neutrons and protons will give the same contribution). We can compare these two expressions to the "cross section of the radiative effects" for electrons

$$\sigma_{\text{rad}} \sim Z^2(e^2/\hbar c)r_0^2 = (Z^2/137)r_0^2$$

and find the ratios

$$\frac{\sigma_P}{\sigma_{\text{rad}}} \sim \frac{A}{Z^2} \quad \text{and} \quad \frac{\sigma_h}{\sigma_{\text{rad}}} \sim \frac{A}{Z^2} \text{ o.i.}$$

This would imply that the barytron effects should lead to somewhat but not so very much smaller cross sections than the radiative effects. Unfortunately at the present state of the theory no definite statements can be made regarding the numerical factors which might also contain homogeneous functions of the involved energies. The above estimates seem to give not unreasonable results if the factors are assumed to be of the order unity as will be shown elsewhere.

Even if we have not yet a definite form for the barytron theory it seems to offer quite good prospects for an understanding of the hard component and it is, anyhow, the only suggestion so far made which gives any clue as to its nature.

THEORY OF ENERGY LOSSES OF HIGH ENERGY PARTICLES BY L. W. NORDHEIM, Ph.D.

DISCUSSION

BY

DR. W. F. G. SWANN.

I have three comments. The first concerns the use of the Gross analysis for high altitudes. Our observations in the National Geographic U. S. Army Air Corps stratosphere flight and in the Piccard flight showed that in spite of the fact that the intensity diminishes rapidly with increase of zenith angle at low altitudes, the decrease becomes less and less until, at the highest altitude attained in the last of these flights, our counters recorded practically as much intensity in the horizontal as in the vertical direction. This flattening out of the intensity zenith angle curve was a perfectly definite phenomenon, showing a consistently progressing increase with altitude; and it is not explicable as regards magnitude by the smaller horizontal thickness of the atmosphere at high altitudes. It would seem that these considerations should have a distinct bearing upon the validity of the application of the Gross analysis of high altitudes.

Secondly, I should like to call attention to the remarkable way in which a distribution function of the form $F(E) = A/E^p$ becomes involved in theories of entirely different types and with a coefficient p which is very much the same in all cases. Thus, Dr. Nordheim's theory has $p = 2.87$; Dr. Johnson deduces a p line between 2 and 3. On the basis of a theory showing radical differences from those discussed today, I arrived, two years ago, at $p = 2.5$; and I believe that Zanstra, about the same time, arrived from other considerations at a p of about the same size.

My third comment concerns energy loss by ionization in such a substance as lead. Many years ago, N. Bohr gave as a primary objection to the classical theory of ionization that it predicted an infinite loss of energy per unit of path, and for

this reason he introduced oscillators into the atom. While the whole classical theory was, of course, inadequate for other reasons, I have never felt the force of this particular reason. The infinity, which is a logarithmic one, comes from parts of space infinitely distant from the ionizing electron, so that, to present the case in its most dramatic light, an electron traveling horizontally a mile above the sea would appear on this basis to lose all of its energy in an infinitesimal distance, on account of the terrible electronic agitation which is set up in the sea. The solution of the paradox now becomes evident. There would be an induced charge on the surface of the sea and this would shield the electron from the opportunity to dissipate its energy in the way cited. In classical theory *the very act of production of electronic displacement*, which is the accompaniment of ionization, produces a doublet separation which acts as a shield preventing the electron's field from reaching to infinite distances.

Now, in the case of quantum mechanics ionization is a phenomenon of distant encounters; and the distance at which maximum ionization occurs can be very considerable for high energies. I believe that as a drastic example W. Wilson quoted a distance of 20 cm. for an electron having an energy of 10^{13} e.v. This is doubtless an artificial example, but even for lower energies one is concerned with distances which represent many atomic diameters, so that in a substance like lead we should expect many atoms to intervene between the electrons and the point where maximum ionization would ordinarily be calculated as occurring. Now it is of the essence of the problem that the very same ψ perturbation which is responsible for ionization is itself instrumental in bringing into existence a polarization which has the effect of a shield and would seem, therefore, to possess potentialities for diminishing the actual ionization below that calculated.

Commenting on the foregoing, Dr. Nordheim has remarked that since light can travel several molecular diameters in lead, it would appear that absorption would not be operative to suddenly changing fields whose time of existence was comparable with the period of a light wave. To this comment, W. F. G. Swann replied that the situation of a light wave is different, for here the displacement produced by the light

wave in the adjoining matter is transverse to the line joining the point of origin to the point where the wave is considered as operative, so that this displacement has no "shielding" action. The whole story of the mutual reactions of these phenomena is, indeed, told in the alteration in velocity produced by the medium. It is only by the introduction of additional damping forces that one obtains any absorption at all. In the case I have discussed concerning ionization, the polarization field is in the line joining the ionizing electron to the atom upon which it is acting. It is, therefore, of a type to produce shielding—not absorption—and no question of the shortness of duration can be invoked to eliminate the phenomenon, because, as already remarked, this phenomenon of polarization is simply another aspect of the very phenomenon which creates the ionization itself.

PRIMARY AND SECONDARY COSMIC RAYS, SHOWERS AND BURSTS.*

BY

W. M. NIELSEN, Ph.D.,

Duke University, Durham, N. C.

I. INTRODUCTION.

A considerable number of the general features of cosmic ray phenomena are now understandable on the view that a part of the radiation is made up of electrons and photons which obey the usual laws of radiation. Theoretical studies have, however, indicated that the expected intensity of the radiation at sea level is larger than would be predicted by this theory and have pointed to the existence of a more penetrating type of radiation. The presence of such a component in the cosmic radiation has been experimentally demonstrated. Rossi [1] and his co-workers, Auger and Ehrenfest,[2] and Street, Woodward and Stevenson [3] have shown that there are ionizing particles in the cosmic radiation which are capable of penetrating at least a meter of lead, whereas according to the theory no electron of reasonable energy should penetrate through more than approximately 15 centimeters of lead. The conception of two components in the cosmic radiation distinguishable by their penetrating power has been supported for some time by Auger [4] and his coworkers. Measurements made at sea level show that about 25 per cent. of the particles are absorbed in about 10 centimeters of lead. This portion is usually referred to as the soft component. Another meter of lead reduces the number of particles by about an additional 30 per cent. This group is called the penetrating component.

* Based upon a paper read at the Chicago Cosmic Ray Symposium, June 29–30, 1938.

[1] Rossi, Int. Conf. Nucl. Physics, London (1934).

[2] Auger and Ehrenfest, *C. R. Acad. Sci. Paris*, **199**, 1609 (1934).

[3] Street, Woodward and Stevenson, *Phys. Rev.*, **47**, 891 (1935).

[4] Auger and Leprince-Ringuet, *C. R. Sci. Paris*, **199**, 785 (1934).

The soft group is certainly composed of electrons and positrons and their accompanying photons and, as such, are associated with cosmic-ray showers, particularly for the first part of the transition curve.

The nature of the penetrating component is, in many respects, not entirely clear. Our attention will therefore be largely directed to a discussion of certain experiments which bear on this problem.

II. THE NATURE OF THE PENETRATING COMPONENT.

We mention here first the measurements of Ehmert [5] and V. Wilson,[6] who have made counter measurements of the intensity under thick layers of water and rock respectively. Their results are shown in Fig. 1 in which the cosmic-ray intensity is plotted as a function of depth below the top of the atmosphere. Wilson suggests that the rays are made up of two kinds evidenced by the break in the curve at 250 meters water equivalent. He suggested that it was not impossible that one of the components consists of heavy electrons and the other of neutrinos.

We have recently completed an investigation [7] with K. Z. Morgan designed to throw some light on the nature of the ionizing particles in such underground experiments. The work was performed at Linville Caverns in western North Carolina. The experiment was one in which one measures the absorption of the rays in lead placed between a train of counters. Measurements were made inside the cavern at a depth below the top of the atmosphere of approximately 70 meters water equivalent and at the mouth of the cavern. The results obtained inside are shown in Fig. 2. The data obtained outside are shown in Fig. 3. A comparison of the two curves shows that:

(1) The observed hardening of the radiation with depth is to be associated with ionizing particles.

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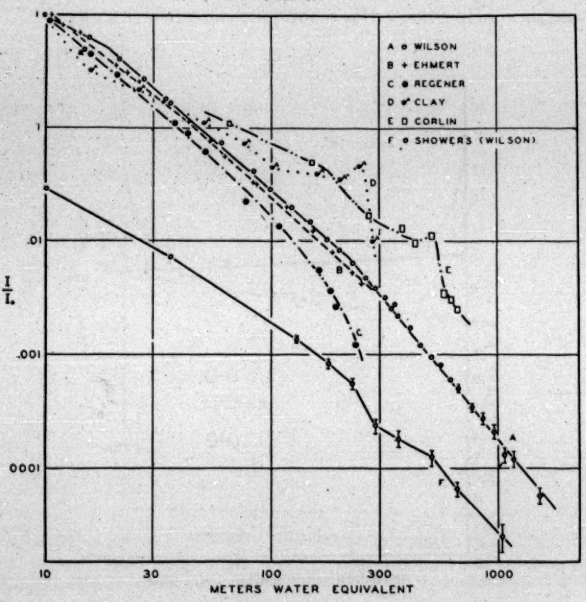
[5] A. Ehmert, *Zeits. f. Phys.*, **106**, 751 (1937).

[6] V. C. Wilson, *Phys. Rev.*, **53**, 337 (1938). See the literature there cited for earlier intensity-depth measurements.

[7] A report on this work was presented at the Washington Meeting of the American Physical Society, April 1938.

(2) The smallness of the absorption of the hard radiation inside the cavern makes it unnecessary to assume that non-ionizing particles (e.g. neutrinos) are involved in the transmission of cosmic-ray energy down to these depths.

FIG. 1.



Cosmic-ray intensity plotted on a logarithmetic scale *versus* the depth from the top of the atmosphere plotted on a logarithmetic scale. (V. Wilson.)

(3) The percentage of soft radiation is just about the same inside and outside the cavern, 25 and 35 per cent. respectively.

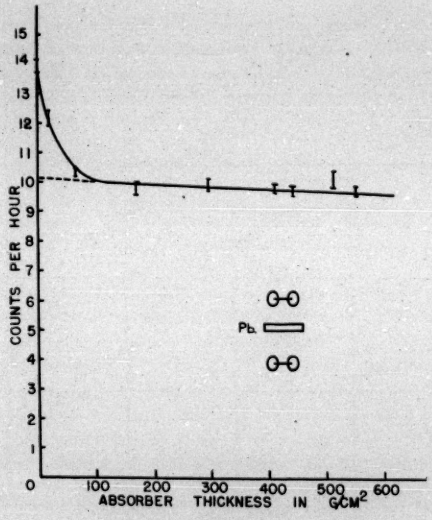
(4) The underground absorption curve shows the presence of secondaries of considerable energy.

The near equality between the percentage of soft radiation inside and outside the cavern suggests an equilibrium between

the hard and soft components. There is a possibility that the percentage of soft radiation passes through a minimum between 70 meters water equivalent and the earth's surface in which case the equality would have another significance.

Wilson [8] in some later work in which, however, he placed absorbers above and between the counters, has come to similar conclusions. His results are shown in Fig. 4.

FIG. 2.



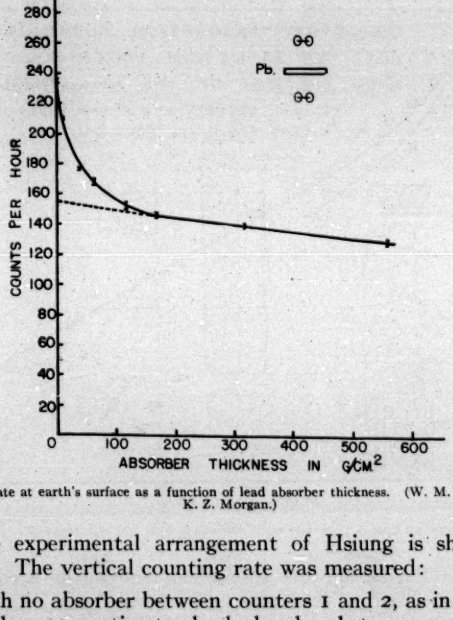
Counting rates inside cavern as a function of lead absorber thickness. (W. M. Nielsen and K. Z. Morgan.)

The existence of penetrating particles which are capable of transmitting cosmic-ray energy down to depths at least equivalent to 250 meters water can therefore be regarded as established. It does not seem possible at the present time to make any decision as to whether or not this penetrating radiation is a separate component falling on our outer atmos-

[8] V. Wilson, *Phys. Rev.*, 53, 908 (1938).

phere or whether it is generated in some way by the soft component. Some evidence exists for the generation of a penetrating radiation in the passage of the cosmic radiation through matter. We shall next consider, therefore, certain experiments of Hsiung [9] and Maass [10] designed to test this possibility.

FIG. 3.



Counting rate at earth's surface as a function of lead absorber thickness. (W. M. Nielsen and K. Z. Morgan.)

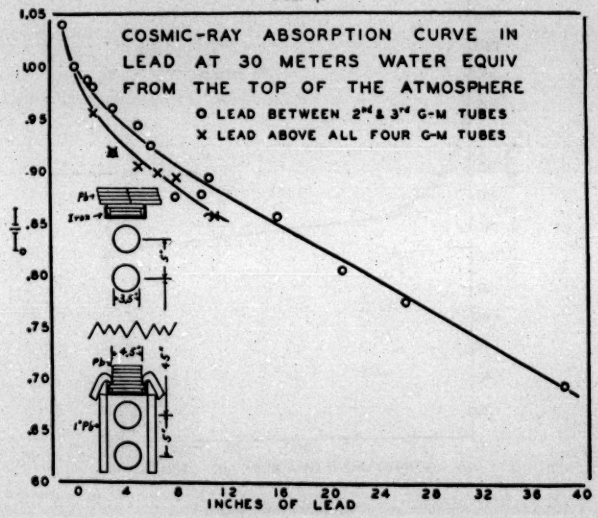
The experimental arrangement of Hsiung is shown in Fig. 5. The vertical counting rate was measured:

(1) with no absorber between counters 1 and 2, as in *A*,
(2) with a 20 centimeter lead absorber between counters 1 and 2, as in *B*,
(3) and with a 20 centimeter lead absorber above all the counters, as in *C*.

[9] D. S. Hsiung, *Phys. Rev.*, **46**, 653 (1934).
[10] H. Maass, *Ann. d. Physik*, **27**, 507 (1936).

For each series of measurements a constant lead absorber (2.5 centimeters) was placed around counter 3. The observed counting rates are also shown in the figure. Hsiung concluded that the reduction in the number of counts with the absorber in position B was slightly greater than in position C, that coincidences are due chiefly to penetrating ionizing particles, and that the slight increase in counting rate in

FIG. 4.

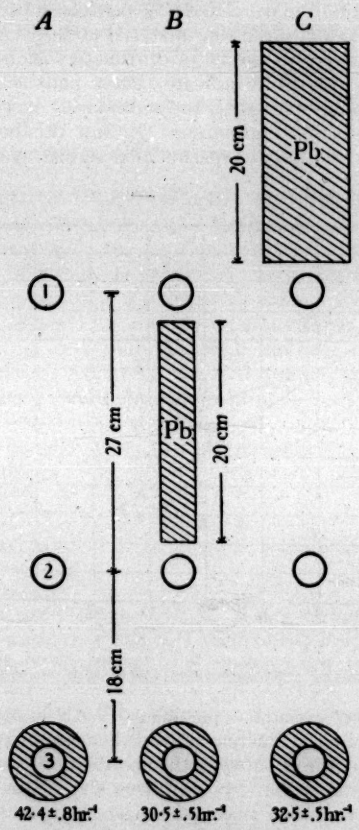


Absorption curve in lead at 30 meters water equivalent from top of atmosphere. (V. Wilson.)

position C may be due to secondaries which accompany primaries which pass through shielded counter 3.

The experimental arrangement of Maass is shown in the insert of Fig. 6. The vertical counting rate for various thicknesses of iron absorber between the counters is shown by the curve A. Curve B corresponds to the observed counting rate when the absorbing material fills the cone above the counters as shown in the figure. The higher counting rate

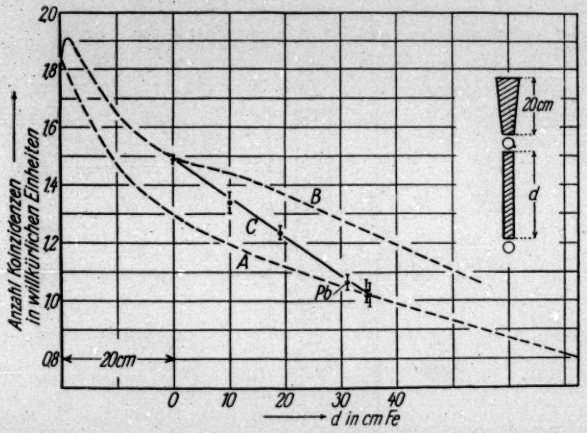
FIG. 5.



Hsuing's coincidence experiment.

for small absorber thicknesses corresponding to the later condition is undoubtedly associated with the soft component of the radiation. The difference persists however out to large thicknesses of absorbing material and, in fact, seems to show a maximum at about 35 centimeters of iron. Maass interprets his results to indicate that a neutral radiation is involved (possibly photons), the secondaries of which have a range in iron of 35 centimeters. To test this conclusion he performed an additional experiment designed to measure the

FIG. 6.



Cosmic-ray absorption curves with absorber between counters (*A*), and with absorber above counters (*B*). The curve *C* shows the absorption of the secondary hard radiation. (Maass.)

range of these secondary particles. With a constant iron thickness of 20 centimeters above the counters, he placed various layers of iron between the counters. The decrease in counting rate is shown by the curve *C*. From the results obtained he concluded that the range of the secondary particles was 35 centimeters of iron. Obviously this is not accurately determined. Very likely a portion of the difference between the curves *A* and *B* may be due to secondary radiation generated by particles directed in such a way as not to

pass through both counters. The curve C suggests however, that a portion at least of the additional radiation generated in the iron has a range much greater than is ordinarily associated with the soft component. While all of the difference between the curves A and B may not be due to a more penetrating type of radiation, these careful measurements of Maass strongly suggest that such a radiation is generated in the iron when exposed to cosmic radiation. These measurements should be extended to different materials.

III. The Variation of the Hard and Soft Component above Sea Level.

In spite of the considerable number of measurements of the cosmic-ray intensity as a function of altitude, we still lack precise data on the variation of the intensities of the separate components as a function of altitude. Qualitatively we can say, as has been emphasized many times, that the soft radiation is not in equilibrium with the hard in our atmosphere. Thus for example, Auger, Ehrenfest and Leprince-Ringuet [11] have made measurements at sea level and at Jungfraujock with results as shown in Table I, in which the relative abundance of the two components at the two elevations are shown.

Table I.

	Jungfrau	Sea Level
Hard Group	190	120
Soft Group	170	25–30

A comparison of the results shows immediately, in a qualitative way, that the soft component has increased by several hundred percent while the penetrating component has only increased by about 60 percent between sea level and Jungfraujock. It will be appreciated that measurements of this kind are extremely difficult, so that we can only regard this evidence as indicating the non-equilibrium between the hard and the soft components. Additional evidence for the non-equilibrium between the soft and hard radiations is contained in numerous depth ionization measurements such as those of Compton and Stephenson,[12] Bowen, Millikan and

[11] Auger, Ehrenfest and Leprince-Ringuet, *J. de Phys.*, **7**, 58 (1936).

[12] Compton and Stephenson, *Phys. Rev.*, **51**, 220 (1934).

Neher,[13] etc. It would appear that additional measurements are needed before we can say anything at all of a precise nature as to the relative abundance of the hard and soft components as a function of altitude. One would also expect that such measurements might be performed in such a way as to throw additional light on the hardening of the radiation as it penetrates the atmosphere. Quantitative questions concerned with the penetration of the soft component through the atmosphere cannot be answered immediately from such measurements, particularly those made at low altitude and below sea level. This is due to the fact that the penetrating rays themselves generate soft particles as already discussed. The possibility that fairly penetrating particles are generated in the passage of cosmic radiation through matter as indicated in the measurements previously described makes it highly desirable that additional measurements of this kind be made at various altitudes.

IV. SHOWERS AND BURSTS GENERATED BY THE SOFT COMPONENT.

1. *Variation with Altitude.*—It has often been noted in the literature that the frequency of showers increases with altitude faster than the general radiation. Its course is more nearly parallel to the variation of the soft component. From the numerous results we present here the work of Woodward.[14] The experimental arrangement used by Woodward is shown in Fig. 7. The experimental results obtained at the various elevations indicated by the barometric pressures is shown in Fig. 8. It will be noted that the curves for the higher elevations can be duplicated by multiplying the curves obtained at a lower elevation by a constant factor. This applies not only for the first few centimeters of lead but obtains throughout the range of thicknesses (up to 10 centimeters of Pb). The relative increase in shower and corpuscular intensity is shown in Table II. It will be noted that the ratio of shower to corpuscular intensity increases from 1 at sea level to 2.4 at a barometric pressure of 44 centimeters. We infer from the data that this ratio would also obtain for showers recorded under as much as 10 centimeters of lead.

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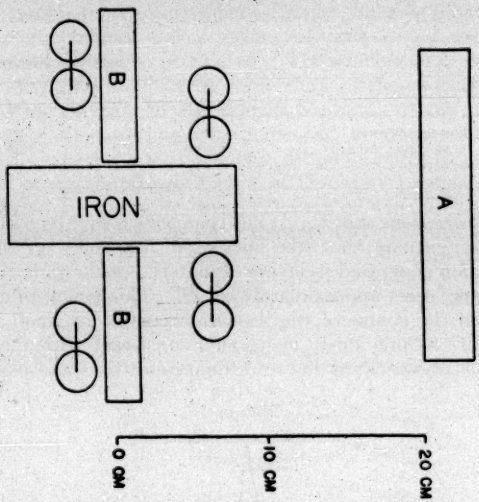
[13] Bowen, Millikan and Neher, Int. Conf. Nucl. Phys. (London).

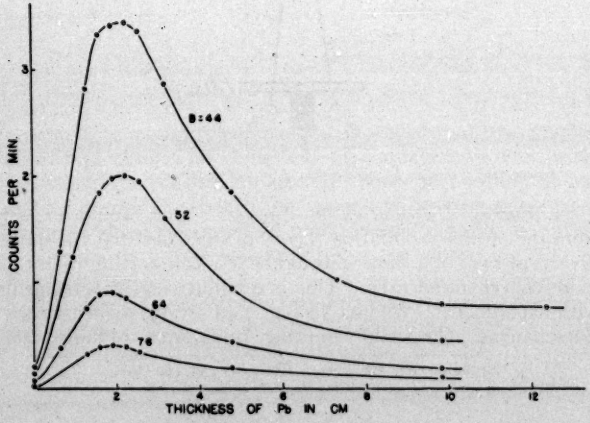
[14] R. H. Woodward, *Phys. Rev.*, 49, 711 (1936).

FIG. 7.



Arrangement of counters for study of showers. (Woodward.)

FIG. 8.



Shower production curves at Mt. Evans (4300 meters), Echo Lake (3250 meters), Denver (1620 meters) and Cambridge (60 meters). (Woodward.)

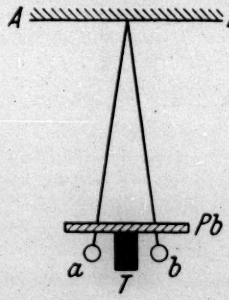
TABLE II.

Ratio of Showers to Corpuscular Intensity at Different Altitudes.

	Barometric pressure (cm.)			
	44	51	64	76
Relative shower intensity	8.5	5.0	2.25	1.00
Relative corpuscular intensity	3.6	2.5	1.46	1.00
Ratio of showers to corpuscular intensity	2.4	2.0	1.5	1.0

2. *Variations with Z.*—It has been shown [15, 16] by a number of investigations that the increased frequency of shower production generated in layers of material of the same atomic thickness varies approximately as Z^2. This general dependence and the course of the transition curves for small thicknesses are as previously mentioned consistent with the view that such showers are due to ordinary electrons and photons.

FIG. 9.



Arrangement of counters for measurement of two fold coincidences. (Barschaukas.)

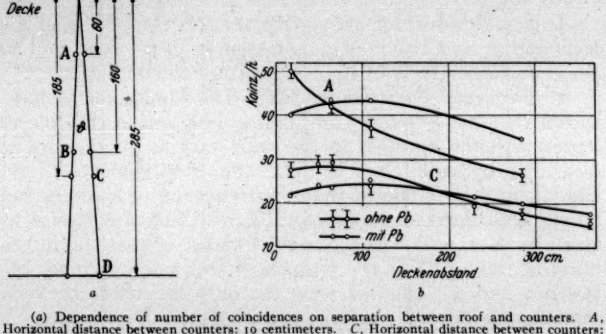
3. *Energy Distribution of Showers.*—One would expect from the ordinary radiation theory of electrons that the more divergent rays of a shower would be less penetrating than the more concentrated rays. This is qualitatively in agreement with experiment. We give in Fig. 9 an arrangement used by Barschaukas. Two-fold counting rates were obtained for

[15] J. E. Morgan and W. M. Nielsen, *Phys. Rev.*, **50**, 882 (1936).

[16] HuChien Shan and co-workers, *Proc. Roy. Soc.*, **161**, 95 (1937).

showers under a 38 centimeter concrete roof with and without an 0.8 centimeter lead absorber over the counters for various counter separations and counter positions below the roof. The results are shown in Fig. 10. The conclusion is that for rays which are divergent by more than 7° the counting rate decreases with the lead absorber in position. If the angle is less than 7° the counting rate increases. It is not possible as yet to say whether the concentrated bundle of radiation consists of photons and are a part of the same phenomena as represented by the more divergent rays or whether they are to be associated with the hard showers to be discussed later.

FIG. 10.



(*a*) Dependence of number of coincidences on separation between roof and counters. *A*, Horizontal distance between counters: 10 centimeters. *C*, Horizontal distance between counters: 25 centimeters.
(*b*) Position of counters at which pairs of curves *A* and *C* intersect. (Barschaukas.)

It should be perhaps emphasized however that the results referred to above are consistent in a qualitative way with the assumption that we are here only concerned with ordinary electron showers. It is to be expected that the more concentrated showers consist of more energetic particles. The probability that they will multiply in the absorbing lead is therefore greater.

We take up next very briefly certain problems associated with bursts.

1. *Variation with Altitude.*—We give in Table III a few data comparing the relative intensities of corpuscular rays,

showers, small bursts and large bursts between sea level and an altitude of 4300 meters.

TABLE III.

Variation with Altitude of Corpuscular Rays, Small Showers and Bursts.

	Barometer pressure (cm.)			
	76	64	51	44
Relative corpuscular intensity.....	1.00	1.46	2.5	3.6 (Woodward)
Relative shower intensity (small)...	1.00	2.25	5.0	8.5 (Woodward)
Relative bursts (small 10–15 rays)..	1.00			9.0 (Young)
Relative bursts (30 or more rays)..	1.00			22.0 (Young)
Relative bursts (100 or more rays).	1.00			26.6 (Montgomery)
Relative soft intensity (estimate)...	1.00			7.2

It is assumed in the above that the soft component at sea level and at an altitude of 4300 meters is 30 per cent. and 60 per cent. respectively of the total corpuscular radiation.

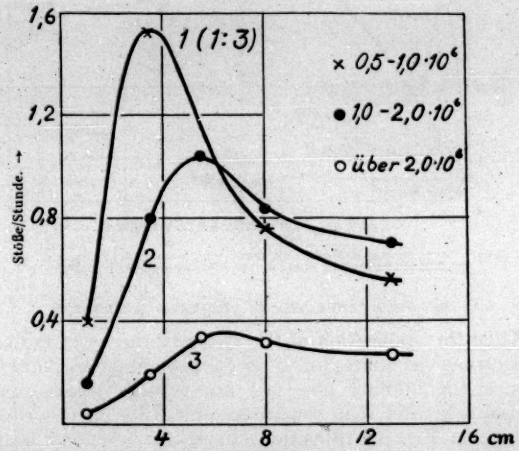
2. *Frequency Variation in Size.*—The Montgomerys have shown that the frequency of burst production in thin plates varies with the material in the same way as do showers as measured by counters. In fact, the Montgomerys [17] and Ehrenberg [18] have shown that the frequency of showers and bursts both decrease monotonically with increase in size as given by $N \sim 1/S^n$ where S is the number of particles in the burst or shower, N is the frequency, and n is a number between 2 and 3. On this view the only difference between showers and bursts is the large variation in their frequency.

3. *Average Range of Bursts.*—Nie [19] and Messerschmidt [20] have measured the range of the radiation involved in bursts by placing layers of lead between adjacent ionization chambers. They arrived at an average range of from 4 to 6 centimeters. Carmichal [21] and Boggild [22] by similar methods find a smaller value. It would seem that the average range of bursts is somewhere between 2 and 6 centimeters of lead.

[17] C. G. and D. D. Montgomery, *Phys. Rev.*, **47**, 429 (1935).
[18] W. Ehrenberg, *Proc. Roy. Soc.*, **155**, 532 (1936).
[19] Heinz Nie, *Zeits. f. Phys.*, **99**, 453, 776 (1936).
[20] W. Messerschmidt, *Zeits. f. Phys.*, **103**, 27 (1936).
[21] H. Carmichal, *Proc. Roy. Soc.*, **154**, 223 (1936).
[22] J. K. Boggild, Diss. Kopenhagen (1937).

4. *Bursts as a Function of Material Thickness.*—We give in Fig. 11 the measurements of Boggild [22] showing burst frequency in iron. It will be noted that the iron thickness corresponding to the maximum increases with the size of burst. This fact would indicate that the processes involved in the production of some of the bursts are the same as those dealt with in the electron theory of multiplication of showers.

FIG. 11.

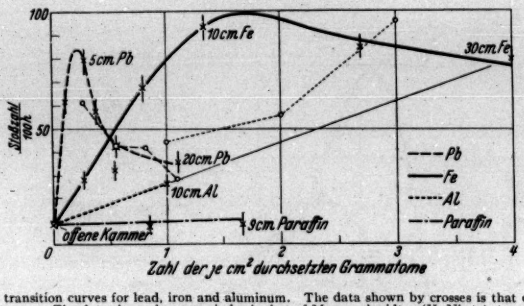


Transition curves for bursts in iron: curve 1, small bursts; curve 2, medium bursts; curve 3, large bursts. (Boggild.)

The decrease in the number of bursts which follow the maximum must correspond to the absorption of the radiation responsible for the bursts. This implies again that at least a part of the radiation is to be associated with the soft component. Experimentally, one does not find that the curve decreases at large thicknesses toward zero. It appears that some of the bursts must be associated with a more penetrating type of radiation. We have already referred to the fact that the burst frequency in thin layers of material varies in the

same way as do showers. The results of Nie shown in Fig. 12 indicate that this does not obtain for large thicknesses of material. It should be pointed out, however, that the results of burst experiments are very sensitive to external surroundings so that at present the problem is in a very unsatisfactory state experimentally.

FIG. 12.



Burst transition curves for lead, iron and aluminum. The data shown by crosses is that of Nie. The data shown by open circles is that of Messerschmidt. (H. Nie.)

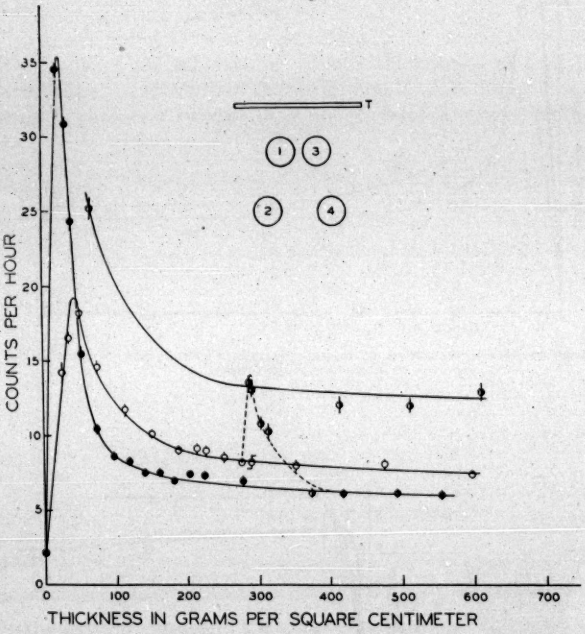
V. SHOWERS GENERATED BY THE HARD COMPONENT.

While the application of the ordinary theory of radiation to electrons accounts for a large percentage of observed showers, the number observed under large thicknesses of material is greater than can be accounted for on this theory. We give in Fig. 13 transition curves for iron and lead as observed by Morgan and Nielsen.[23] The dashed curve in this figure represents the iron to lead transition. These results show that the showers under heavy layers multiply in the same way as do those of the soft component. It is only necessary to assume that shower producing radiation (electrons and photons) are produced in the lower layers of material above the counters. Fig. 14 shows the lead to iron transition. This curve, of course, as do those presented in the previous figure, shows the electronic character of the showers under thick layers. These results must be regarded as strong evidence for the generation of secondary radiation of electronic

[23] K. Z. Morgan and W. M. Nielsen, *Phys. Rev.*, **52**, 432 (1937).

character of considerable energy by the penetrating particles in their passage through matter. It would appear that observations of Schwegler [24] may be interpreted in the same way.

FIG. 13.

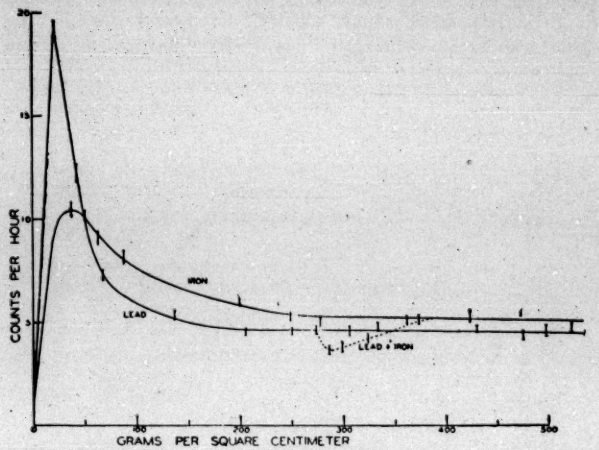


Shower transition curves for lead (filled circles), and for iron (open circles). The dotted curve shows the iron to lead transition under 274 g./cm². of iron. (K. Z. Morgan and W. M. Nielsen.)

Fig. 15 shows the experimental arrangement used by him and the results obtained. The 10 centimeter lead block *F* in the figure was kept constant. The increased counting rate was observed for layers of different materials placed at *S*. We notice that for lead, saturation is attained in from 10 to

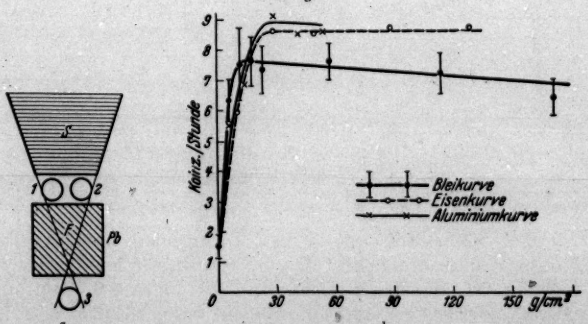
[24] A. Schwegler, *Zeits. f. Physik*, **96**, 62 (1935).

FIG. 14.



Shower transition curves showing the iron to lead transition under 274 g./cm². of lead. (K. Z. Morgan and W. M. Nielsen.)

FIG. 15.

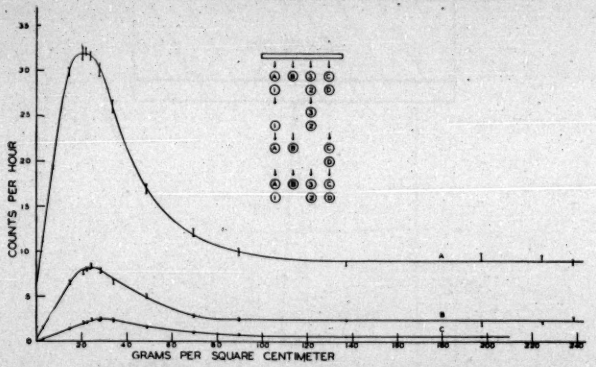


(*a*) Arrangement for measurement of showers.
(*b*) Shower frequency as a function of material thickness at *S* with a fixed lead absorber at F (Schwegler.)

20 g./cm.^{2} (larger for Fe and Al) after which the counting rate decreases slowly, more like the decrease of the hard component than the soft. It will also be noticed that the equilibrium shower intensity is greater for iron than for lead. These earlier results of Schwegler are entirely consistent with the interpretation we have given to the results of Morgan and Nielsen mentioned above.

An attempt has been made to study the variation of the frequency of the showers in various thicknesses of lead in some unpublished work of the writer and K. Z. Morgan shown in Fig. 16. The curves *A*, *B* and *C* refer to the observed

FIG. 16.



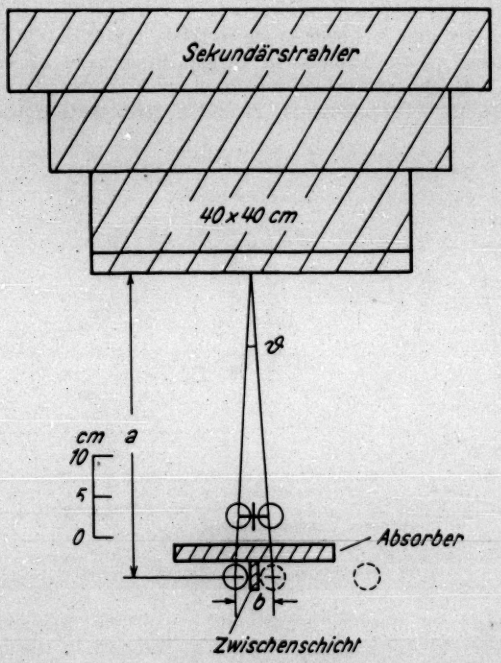
Shower transition curves in lead for two-fold coincidences (*A*), three-fold coincidences (*B*), and four-fold coincidences (*C*). (K. Z. Morgan and W. M. Nielsen.)

frequency of double, triple and quadruple coincidences measured by the counter arrangement shown in the inset. In a very qualitative way there does not seem to be much variation in the complexity of the showers as measured by the ratio of doubles to triples and doubles to quadruples. It should be pointed out that counters are more sensitive to the larger showers so there is some doubt as to the proper interpretation of these results.

VI. THE GENERATION OF HARD SHOWERS.

We consider next a series of observations of Bothe and Schmeizer [25] on showers which diverge but slightly, the so-called hard showers. We give in Fig. 17 their experimental

FIG. 17.



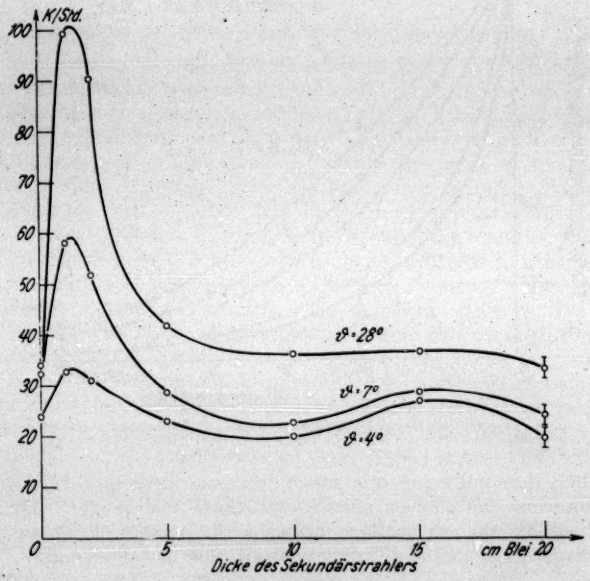
Arrangement for measurement of Rossi transition curves and for absorption of shower particles. (Bothe and Schmeizer.)

arrangement and in Fig. 18 the transition curves for divergence angles of 4°, 7° and 28°. The second maximum at about 15 centimeters of Pb is apparently more pronounced for the

[25] K. Schmeizer and W. Bothe, *Ann. d. Physik*, **32**, 161 (1938).

small angle showers. If the errors shown for the point at 20 centimeters are representative of the rest, this maximum need not be so definite as they have indicated. It should be borne in mind in any comparison of these curves that the variation in divergence angle was obtained by varying the distance between the counter assembly and the lower layer of

FIG. 18.

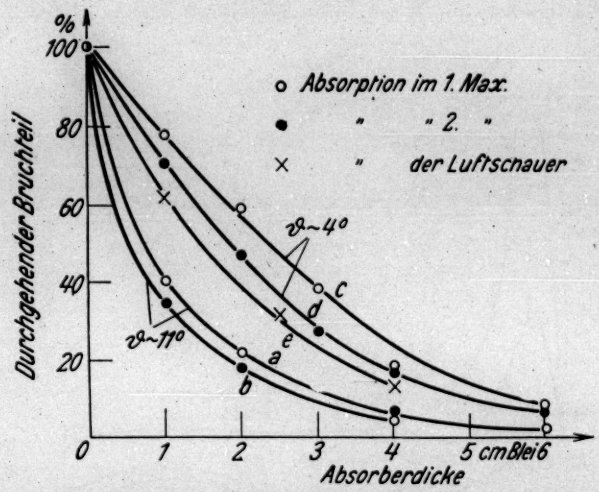


Rossi transition curves for showers of different angular divergence. (Bothe and Schmeizer.)

lead. Viewed in this light it would appear that the decrease, say for the first maximum in the transition curve, is much greater than for a thickness in the region of the second maximum. They have also made measurements on the absorption of such shower particles, the results of which are shown in Fig. 19. The data indicate that the 4° showers are

more penetrating than the 11° showers. Measurements on the absorption of the showers are also shown for the thicknesses corresponding to the first and second maximum.

FIG. 19.



Absorption of showers produced in lead of different thicknesses. The curves also show the difference in the absorption of showers of different angular divergence. (Bothe and Schmeizer.)

There does not seem to be much difference in the penetrating power of the shower particles at these two points. The possibility that we are here dealing with electrons of different energy is not excluded by these absorption measurements.

SOME REMARKS ON THE PRODUCTION OF SHOWERS BY COSMIC RAYS.*

BY

C. G. MONTGOMERY, Ph.D., and D. D. MONTGOMERY, M.S.

Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

VARIATION OF SHOWER PRODUCTION WITH ATOMIC NUMBER.

A number of investigators, such as Rossi, Nie, Nielson, and ourselves, have measured the variation of shower production with atomic number, and have reported it to vary closely as Z^2. This has been considered by many to offer confirmatory evidence in favor of the cascade theory of shower production. However, some deviations from a simple Z^2 law have also been reported and, in the hope of clarifying the situation, we should like to present the following remarks. In investigations of this kind, the usual procedure is to observe the number of showers with and without various materials over the detecting apparatus. The number of showers occurring when no material is present is treated as a zero reading and subtracted from the number of showers occurring beneath the material. The remaining number is considered as being produced by the material present. If the showers are produced by a multiplicative process, this procedure is extremely difficult to justify, and we must make a more detailed analysis of what happens.

Let us consider two extreme cases, one in which there is a very small background, the other in which the "zero count" is large, as when observations are taken indoors. Most of the observations have been made under conditions closer to the second case than to the first. Now when the conditions of the first case obtain, the cascade theory of showers predicts a much faster variation with Z than Z^2. This is easy to see, since, according to the theory, thicknesses of different materials which are proportional to $1/Z^2$ have the same shower producing capacity in so far as high energy shower rays are con-

* Based upon a paper read at the Chicago Cosmic Ray Symposium, June 29–30, 1938.

cerned. However, in materials of high atomic number, multiplication will continue to lower energies in such a way that the total number of rays in showers emerging from equivalent thicknesses of different materials is proportional to Z. This, together with the observation that the number of showers greater than a given size is inversely proportional to the square of the size of the shower, leads to a variation with Z of a shower producing capacity per atom which is approximately Z^4.

Observations, out of doors, to test this point are under way at the present time, and the results already obtained show that the variation with Z is much faster than Z^2. The number of showers from 21 cms. of magnesium should be about the same as from one centimeter of lead, if a Z^2 law were valid. We observed, however, only 1/3.2 as many showers from this thickness of magnesium as from one centimeter of lead, no zero reading being subtracted. We cannot say, at the present time, what power of Z our observations indicate, since the "background" showers are not completely eliminated. We shall return to this point a little later.

We may summarize the situation, then, in this way: That in those cases where a Z^2 law has been reported, the phenomenon which was measured was primarily the result of an increase in size of the showers falling upon the apparatus; while when the "background" rate is reduced, one more nearly approaches the ideal case of only single rays falling upon the apparatus and the measurements conform more closely to the variation with atomic number predicted by the cascade theory, that is, Z^4.

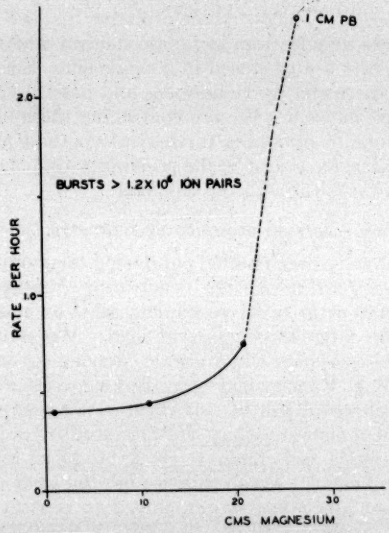
SHOWERS OF THE EXPLOSION TYPE.

We have recently presented evidence [1] to show that there is no necessity to invoke any mechanism other than the ordinary multiplicative process to explain even the largest showers produced in small thicknesses of material. However, some observations which we have recently made seem to point to the existence of a small number of showers which may arise from a different type of process. We have attempted, for the measurements on the variation of shower production

[1] C. G. and D. D. Montgomery, *Phys. Rev.*, **53**, 955 (1938).

with atomic number mentioned above, to reduce as far as possible the number of showers observed in an ionization chamber when no shower producing material was placed over it. For this purpose we employed a spherical chamber about 40 cms. in diameter constructed with one centimeter magnesium walls, and containing nitrogen at 14.5 atmospheres pressure. The observations were carried out in a wooden

FIG. 1.



Large showers observed under various thicknesses of magnesium. The point labelled 1 cm. of lead is plotted at the equivalent thickness of magnesium on a Z^2 basis.

structure on the roof of the Bartol Research Foundation. In this way only one centimeter of magnesium and about 2.5 cms. of wood were present above the chamber. Some showers were still observed. To determine whether these originated in the magnesium, more magnesium was placed over the chamber and observations taken. These data are illustrated in Fig. 1. If the showers had originated in the magnesium walls

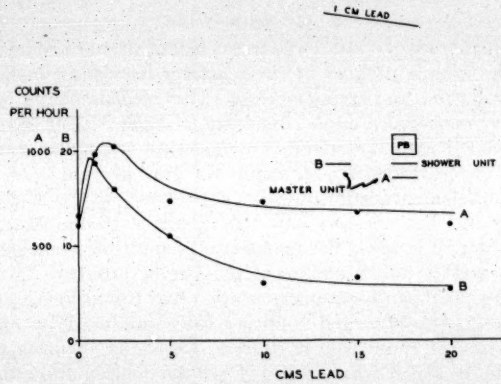
of the chamber, we should have expected that the extrapolation of the curve would pass through the origin. Since it does not, we must conclude that the source of showers is not the magnesium and there remains only the air above the apparatus to act as the shower producing material. However, if these showers are produced by the ordinary multiplicative process, the spreading of the rays of the shower would be so great that we should hardly ever expect as many as the hundred or more rays that we observe to pass through the chamber simultaneously. Thus it seems probable that we are dealing with showers arising from some mechanism whereby a large number of rays are produced in a single act. Such processes have been discussed by Heisenberg and have been called explosion type showers. We are continuing these observations with the hope of obtaining further information about them. There remains, for example, the possibility that these showers proceed upwards through the chamber.

SHOWERS PRODUCED BY ELECTRONS.

It has already been pointed out during this symposium how it is necessary to invoke the penetrating component of the cosmic radiation in order to explain why so many showers emerge from large thicknesses of lead. We should like to describe an experiment which are we carrying out in collaboration with W. E. Ramsey and which is designed to make a more direct experimental test of this point. We wish to measure the number of showers which are produced by ordinary electrons or photons and eliminate those produced by the penetrating component. To do this, we use the same device that Neddermeyer and Anderson employed to separate electrons in order to measure their energy losses in the cloud chamber, namely, we select only parts of showers formed above the apparatus to produce the showers which we measure. The apparatus is schematically indicated to scale in Fig. 2. We have a large plate of lead to act as the primary source of electrons. These electrons fall simultaneously on a pile of lead plates and on a master counter unit placed in position *B*. As electrons pass through the pile of plates, showers are produced which are detected by the shower unit below the pile. The Rossi curve obtained with this arrangement is labelled *B*

in the figure. These showers are thus produced by electrons or photons, and the effect of the penetrating component is largely eliminated. To measure all the showers produced in the pile of lead plates, the master unit is placed in position A, and the Rossi curve labelled A obtained. Curves A and B are plotted with different scales of ordinates so as to make the ordinates of the two curves about the same at the optimum thickness. It is seen that at large thicknesses the number of showers produced by electrons falls considerably below the

FIG. 2.



Curve A, showers produced by electrons and penetrating rays. Curve B, showers produced by electrons.

number of showers produced by both electrons and penetrating rays. Although the observations show that there are still some showers at large thicknesses on curve B, we believe that this is to be ascribed to the incomplete elimination of the penetrating rays. We, therefore, conclude that it is justifiable to separate a Rossi curve into two portions, one of which is produced by soft rays, ordinary electrons and photons, and which disappears in the neighborhood of 10 cms. of lead. The other portion is produced by penetrating particles and extends to much larger thicknesses.

"PRIMARY AND SECONDARY COSMIC RAYS, SHOWERS AND BURSTS."

BY

W. M. NIELSEN, Ph.D.

DISCUSSION BY

J. C. STEARNS, Ph.D., and D. K. FROMAN, Ph.D.

Dr. Stearns.

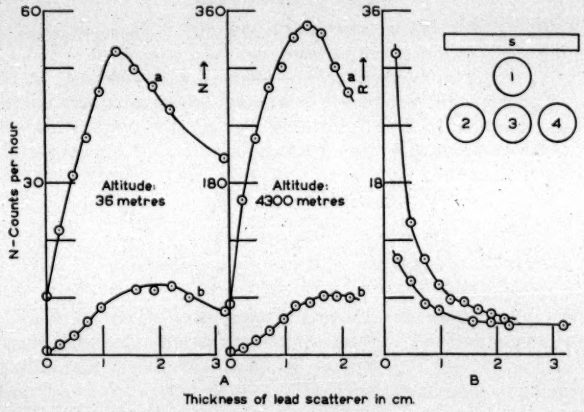
Measurements relating the frequency of shower production with the atomic number of the scatterer have been made at altitudes 1700 and 4300 meters. The measurements were made by means of a triple coincidence Geiger-Müller counter tube system with the counters arranged in triangular formation. Two thicknesses, 4.6 and 7.2 gm. per cm.^{2}, of the following elements were used for scatterers: Al, Fe, Cu, Zn, Sn, Hg and Pb. It was found that, for scatterers of equal masses per unit area, the frequency of multiple coincidence varied roughly as the square of the atomic number, Z. No difference in this approximate relation was found for the two altitudes. The observed counting rates produced by equal thicknesses of these thin scatterers, measured in units proportional to $Z^2\rho/A$ where ρ and A are the density and atomic weight of the scattering material respectively, show somewhat better agreement for the different values of Z.

There is, however, an anomaly in the case of Cu and Zn. Although Zn has the higher atomic number, many more showers were detected from the copper than from the zinc scatterers of the same thickness measured in gm. per cm^2. The copper showed an excess counting rate which was 12 times the probable error of the difference between the rates for copper and zinc. When the thicknesses of the scatterer are measured in units proportional to $Z^2\rho/A$ the agreement between the counting rates for Cu and Zn is improved considerably, but even on this basis, copper is definitely superior to zinc as a producer of showers.

Dr. Froman.

In order to check a possible consequence of the multiplicative theory of shower production, counters were arranged as shown in Fig. 1. The frequencies of multiple coincidence for different thicknesses of the lead scatterer, s, were determined for two different cases: (a) triple coincidence using counters 1, 2 and 3 and (b) quadruple coincidence using counters 1, 2, 3 and 4. In order to actuate the counting system a minimum of two ionizing rays is necessary for triple coincidence and a

FIG. 1.



minimum of three ionizing rays is necessary for quadruple coincidence. The results are shown for two altitudes in Fig. 1*A*. It is seen that these measurements are in qualitative agreement with the multiplicative theory in that (i) for very small thicknesses of lead the triple coincidence rate varies approximately linearly with the thickness of the scatterer whereas the quadruple rate varies as a power of the thickness greater than unity, and (ii) the optimum thickness of the scatterer is greater for quadruple coincidence than it is for triple coincidence.

The ratio, R, of triple to quadruple coincidence rates, corrected by subtracting the counting rates in air, are shown for the two altitudes in Fig. 1*B*. This ratio R, increases rapidly as the thickness of the scatterer is diminished which is in qualitative agreement with the theory of pair production. On the basis of the theory it is expected that, for very thin scatterers, most of the two-particle showers are initiated by incident photons while most of the three-particle showers are initiated by incident electrons. Hence one possible interpretation of the change in the plotted ratio with altitude is that the ratio of the number of photons to the number of electrons in the cosmic rays incident on the scatterer is greater at the higher altitude.

GRAPHICAL ANALYSIS OF SURGES IN MECHANICAL SPRINGS

BY

KALMAN J. DEJUHASZ,

Associate Professor of Engineering Research, The Pennsylvania State College.
Member of The Franklin Institute.

(*Continued from October issue.*)

B. Spring Is Loaded by Mass.

If a mass M is attached to one end of the spring then its change of momentum $M \cdot \Delta v$ will be proportional to the product $\Delta s \cdot \Delta t$, Δs being the surplus (or deficiency) of stress at the spring-end next to the mass over and above that necessary to sustain the mass in static equilibrium, and Δt being the time during which the Δs acts on the mass. Choosing $\Delta t = T_0$ it can be written:

$$M \cdot \Delta v = A \cdot \Delta s \cdot T_0$$

or

$$\frac{\Delta s}{\Delta v} = \frac{M}{A T_0} = \text{const.} = \tan (\pm \gamma).$$

The factor A, determinable from the characteristics of the spring, converts the stress Δs into force. The angle γ defines a directrix having the following property: if the initial condition v, s of the spring element adjoining the mass is defined by point 1 in the $v - s$ diagram, then the condition after the lapse of T_0 interval will be defined by another point 2, and the line connecting the point 1 with point 2 will form an angle γ with the v-axis.

The method of graphical construction will be illustrated by two examples, 1 and 2.

1. *Motion is imparted to the non-loaded end of the spring* (Fig. 23). This case corresponds to a massless carriage-wheel rolling over a bump, the wheel-axle supporting the carriage mass by means of an interposed spring.

It is assumed that initially the mass is at rest and the spring is under the stress s_1 keeping equilibrium with the weight of the

mass (the motion of the mass being assumed vertical); furthermore, it is assumed that for $2T_0$ duration a velocity of v_2 (point 2 in the $v - s$ diagram) is imparted to the mass.

The surge reaching the then stationary mass-end of the spring attains the stress a; the stress-surplus $\overline{1 - a}$ acts on the mass and sets it in motion. In consequence of the motion the

TABLE I.

I. History of Lift-Velocity Constant.

$r = T/T_0$	p	S_{max}/S_a	S_{min}/S_a
$0 < r < 2$	1	$\frac{4}{\pi} \cdot 1$	0
$2 < r < 4$	2	$\frac{4}{\pi} \cdot 2$	$\frac{4}{\pi} \cdot 1$
$4 < r < 6$	3	$\frac{4}{\pi} \cdot 3$	$\frac{4}{\pi} \cdot 2$
↓	↓	↓	↓
$2(p-1) < r < 2p$	p	$\frac{4}{\pi} \cdot p$	$\frac{4}{\pi}(p-1)$

II. History of Lift-Velocity an Isosceles Triangle.

$r = T/T_0$	p	S_{max}/S_a	$r = T/T_0$	p	S_{min}/S_a
$0 < r < 4$	0	$\frac{4}{\pi} \cdot 1$	$0 < r < 2$	0	0
$4 < r < 8$	1	$\frac{4}{\pi}(1 + 2 \cdot 1 - \frac{8}{4})$	$2 < r < 6$	2	$\frac{4}{\pi}(2 - \frac{4}{4})$
$8 < r < 12$	2	$\frac{4}{\pi}(1 + 2 \cdot 2 - \frac{8}{4}(1+2))$	$6 < r < 10$	4	$\frac{4}{\pi}(4 - \frac{16}{4})$
$12 < r < 16$	3	$\frac{4}{\pi}[1 + 2 \cdot 3 - \frac{8}{4}(1+2+3)]$	$10 < r < 14$	6	$\frac{4}{\pi}(6 - \frac{36}{4})$
↓	↓	↓	↓	↓	↓
$4p < r < 4(p+1)$	p	$\frac{4}{\pi}[1 + 2p - \frac{8}{4}p(1+p)]$	$2(p-1) < r < 2(p+1)$	p	$\frac{4}{\pi}p(1-\frac{p}{4})$

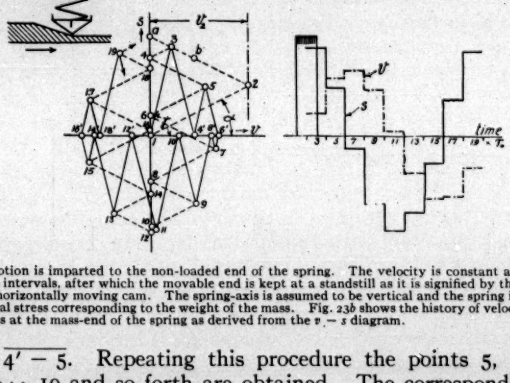
III. History of Lift-Velocity a Sine-Line.

$r = T/T_0$	S_{max}/S_a	$r = T/T_0$	S_{min}/S_a
$0 < r < 3$	$\frac{4}{\pi} \cdot 1$	$0 < r < 2$	0
$3 < r < 5$	$\frac{4}{\pi} 2 \cos \frac{\pi}{4}$	$2 < r < 4$	$\frac{4}{\pi} \sin \frac{2\pi}{4}$
$5 < r < 7$	$\frac{4}{\pi}[1 + 2 \cos \frac{2\pi}{4}]$	$4 < r < 6$	$\frac{4}{\pi}(\sin \frac{2\pi}{4} + \sin \frac{4\pi}{4})$
$7 < r < 9$	$\frac{4}{\pi}[2 \cos \frac{\pi}{4} + 2 \cos \frac{3\pi}{4}]$	$6 < r < 8$	$\frac{4}{\pi}(\sin \frac{4\pi}{4} + \sin \frac{6\pi}{4} + \sin \frac{8\pi}{4})$
$9 < r < 11$	$\frac{4}{\pi}[1 + 2 \cos \frac{2\pi}{4} + 2 \cos \frac{4\pi}{4}]$	$8 < r < 10$	$\frac{4}{\pi}(\sin \frac{2\pi}{4} + \sin \frac{4\pi}{4} + \sin \frac{6\pi}{4} + \sin \frac{8\pi}{4})$

stress decreases along the line $\overline{a - 2}$. After the elapse of T_0 interval the condition of the spring-end adjoining the mass changes to point 3, after the elapse of a further T_0 interval it changes to point b. The mean condition of the mass-end of the spring during these $2T_0$ intervals is defined by point 3, which is the intersection of the directrix $\tan \alpha$ drawn from point 2 (representing the change of state of the mass-end of the

spring) with the directrix tan γ drawn from point 1 (representing the change of velocity of M during one interval T_0, as a function of the spring-stress). When the surge 3 reaches the other end of the spring, it is already at rest (as we assumed that the motion lasts only $2T_0$ intervals), and the stress changes to 4 which surge is reflected again towards the mass M. In the meantime the velocity of the mass is still increasing, according to the v-abscissas of the directrix tan γ, to point 4′ and then to 5 which latter point is found at the intersection of the directrix tan $(-\alpha)$, line $\overline{4-5}$, and of the directrix tan γ,

FIG. 23.



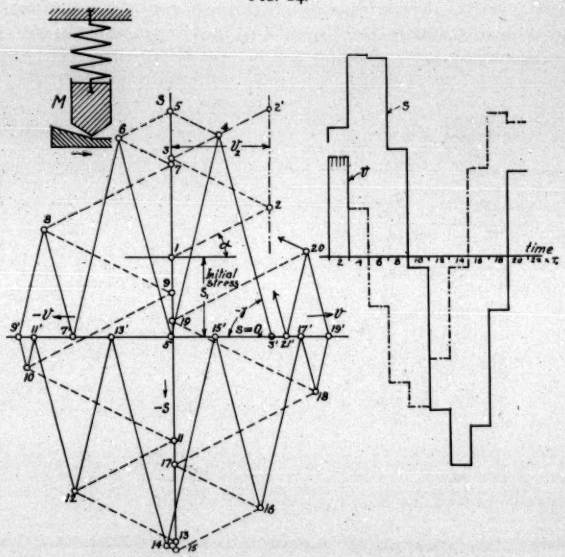
Motion is imparted to the non-loaded end of the spring. The velocity is constant and lasts for $2T_0$ intervals, after which the movable end is kept at a standstill as it is signified by the shape of the horizontally moving cam. The spring-axis is assumed to be vertical and the spring is under an initial stress corresponding to the weight of the mass. Fig. 23*b* shows the history of velocity and of stress at the mass-end of the spring as derived from the $v, -s$ diagram.

line $\overline{4'-5}$. Repeating this procedure the points 5, 7, 9, 11, $\cdots$ 19 and so forth are obtained. The corresponding v and s points, representing the values of velocity and of stress at the mass-end of the spring, can be transferred into the time-diagram as it is shown in Fig. 23*b*.

It is seen that after the termination of the imparted motion the velocity and stress values oscillate above and below their mean $(s = s_1, v = 0)$ values in an approximately harmonic fashion, the velocity values following the stress values with a quarter period difference in phase, i.e., the velocity is greatest when the $s - s_1$ value is zero, and vice versa. This trend

towards harmonic vibration is clearly discernible also from the $v - s$ diagram, as the locus of the values corresponding to the state of spring at the mass-end (points 5, 7, 9 $\cdots$ 19) is approximately an ellipse. The word "approximately" is used advisedly. A true ellipse would be obtainable only with a massless spring assuming an infinite velocity of propagation;

FIG. 24.



Motion is imparted to the mass-loaded end of the spring. The velocity imparted by the cam is constant, it lasts for $2T_0$ intervals, after which the motion of the mass is solely under the influence of the spring. The spring is under an initial stress s_1. Fig. 24*b* shows the history of velocity and of stress at the mass-end of the spring as derived from the $v - s$ diagram.

with a spring having a mass and a finite velocity of propagation the law of motion is contaminated with spring surges and the resulting motion will be not a simple harmonic.

2. *Motion is imparted to the mass-loaded end of the spring, the other end being kept stationary* (Fig. 24). This case corresponds to a value kept on its seat by a spring, and moved by a cam.

It is assumed that initially the mass M is at rest and the spring is under the tension s_1; furthermore it is assumed that the velocity v_2 (point 2 in the $v - s$ diagram) is imparted to the mass for a duration of $2T_0$ intervals and after the completion of the lift the drop of the mass is resisted solely by the spring force.

On reaching the stationary end of the spring the surge 2 is stopped and the stress increased to 3, which latter surge is reflected toward M. At the end of the second interval the velocity of M is v_2 (point 2′) and from this time onward it is diminished by the spring stress. At the end of the third interval, $3T_0$, the condition of the mass-end of the spring will be defined by point 4, being the intersection of the directrix tan α, drawn from the point 3 (representing the change of spring-stress at the mass-end), and of the directrix tan $(-\gamma)$, drawn from point 3′ (representing the change of velocity of M during one interval T_0, as a function of spring-stress). Thus the point 4 defines the mean condition of the mass-end of the spring during the third and fourth intervals. Continuing this procedure the points 6, 8 $\cdots$ 20 and so on have been determined. In this example it was assumed that the mass is firmly attached to the spring, and that after the motion-imparting wedge has passed from under the mass its drop takes place solely under the influence of the spring force. It can be readily seen that under this condition the motion of the mass will be approximately harmonic as it is clearly manifested if the velocity- and stress-coordinates of the points 4, 6, 8 $\cdots$ 20 are transferred into the time-diagram.

If the shape of the cam is such that it prevents the drop of the mass after the completion of the lift, then in the $v - s$ diagram the stress at the mass-end of the spring would not sink below that denfined by the point 3, which in our case corresponds to the static stress corresponding to the full lift.

In our example the mass has overshot the path defined by the cam, i.e., the lift velocity continued (point 4) after the lifting motion of the cam had already terminated. The question arises: what is the criterion for overshooting to take place? The answer is: overshooting will or will not take place depending on whether the point 4 is located in the positive or negative velocity region (i.e., whether the point 4 is on the

right or left side of the s-axis). In our example overshooting could be prevented by a greater initial stress in the spring (i.e., by locating point 1 sufficiently higher on the s-axis) or by a lower lift velocity (by locating point 2 sufficiently close to the s-axis) which conclusions are, of course, in full agreement with previously known theoretical and experimental facts.

In both of our examples (1) and (2) simplifying assumptions were introduced, by using constant, mean values of stress and velocity in successive $2T_0$ intervals. Actually both the stress and velocity are not necessarily constant, but are in general variable. With the expenditure of more labor and greater attention in the graphical construction it would be quite possible to take these variations into consideration, and it may well be warranted to do this in dealing with actual problems. It is believed, however, that the present approximate treatment of the above presented two examples is sufficient to serve as an introduction to this fertile method of investigating spring surges.

APPENDIX.

TRANSIENT PHENOMENA IN ELASTIC SOLIDS.

In elastic solids stressed below the elastic limit the strain is proportional to the stress. Therefore the interrelationship of change in stress and change of velocity in a transient change is closely analogous to that valid for liquids, i.e.:

$$\frac{\text{change of stress}}{\text{change of velocity}} = \frac{\text{modulus of elasticity}}{\text{acoustic velocity}} = \text{constant.}$$

This interrelationship will be derived for several types of springs having engineering importance, taking into consideration their shape and the type of stress to which they are subjected but neglecting the influence of friction and damping.

Once this constant proportionality factor has been determined the graphical construction can be carried out in a manner analogous to the liquid columns, by using this constant factor as the slope of the directrix.[1]

A. Longitudinal Disturbance (Tension or Compression) of a Straight Rod of Constant Cross Section.

According to the law of momentum a force-increment ΔP (over and above the force necessary to maintain the body at

rest) suddenly applied to the end of the rod for Δt time produces a velocity increment Δv in a mass $Fa_l\rho\Delta t$. Therefore it can be written:

$\Delta P\Delta t = Fa_l\rho\Delta t\Delta v.$

Substituting $\Delta P = F\Delta p$,

$$a_l = \sqrt{\frac{E}{\rho}},$$

F = cross sectional area,
E = modulus of longitudinal elasticity,
a_l = velocity of propagation of a longitudinal stress,

the relationship

$$\frac{\Delta p}{\Delta v} = \frac{E}{a_l} = \text{constant}$$

is obtained.

(Example. For steel

$$E = 2{,}200{,}000 \text{ kg. cm.}^{-2} = 31{,}250{,}000 \text{ lb. in.}^{-2}$$
$$= 0.00000795 \text{ kg. cm.}^{-4} \text{ sec.}^2,$$

$$a_l = \sqrt{\frac{E}{\rho}} = 5270 \text{ m. sec.}^{-1} = 17{,}300 \text{ ft. sec.}^{-1},$$

whence

$$\frac{E}{a_l} = 417 \text{ kg. cm.}^{-2}/\text{m. sec.}^{-1} = 1810 \text{ lb. in.}^{-2}/\text{ft. sec.}^{-1}).$$

B. Torsional Disturbance of a Straight Cylindrical Rod.

For rotation the law of momentum can be expressed:

$\Delta M\Delta t = J\rho a_t\Delta t\Delta\omega,$

$$a_t = \sqrt{\frac{G}{\rho}},$$

$$\frac{\Delta M}{\Delta\omega} = J\rho a_t = \frac{JG}{a_t}.$$

J = polar moment of inertia,
M = torque,
ω = angular velocity,
a_t = velocity of propagation of a torsional stress,

Substituting:

$$\Delta M = \frac{J}{a/2}\,\varphi\tau,$$

$$\Delta\omega = \frac{\Delta v}{a/2},$$

G = modulus of torsional elasticity,
τ = shear stress at periphery,
v = velocity of periphery,

whence

$$\frac{\Delta\tau}{\Delta v} = \frac{G}{a_t} = \text{constant.} \qquad d = \text{diameter of rod.}$$

(Example: For steel

$$G = 860{,}000 \text{ kg. cm.}^{-2} = 12{,}200{,}000 \text{ lb. in.}^{-2},$$
$$\rho = 0{,}00000795 \text{ kg. cm.}^{-4} \text{ sec.}^{2},$$
$$d_t = \sqrt{\frac{G}{\rho}} = 3290 \text{ m. sec.}^{-1} = 10{,}800 \text{ ft. sec.}^{-1},$$
$$\frac{G}{a_t} = 261 \text{ kg. cm.}^{-2}/\text{m. sec.}^{-1} = 1130 \text{ lb. in.}^{-2}/\text{ft. sec.}^{-1}).$$

C. Longitudinal Disturbance (Tension or Compression) of a Helical Spring.[3]

The following notations will be used:

L = unstressed length of spring,
n = number of coils,
r = mean radius of coil,
d = diameter of wire,
$F = \frac{d^2\pi}{4}$ = corss sectional area of wire,
$J = \frac{d^4\pi}{32}$ = polar moment of inertia of wire cross section,
ρ = density of wire material,
$Q = 2r\pi n \frac{F}{L}\rho$ = mass of unit length of spring,
$K = \frac{1}{2\pi} G \frac{JL}{nr^3}$ = force necessary to extend the spring by its original unstressed length,
$a_s = \sqrt{\frac{K}{Q}} = \sqrt{\frac{G}{\rho}} \cdot \sqrt{\frac{J}{Fr^2}} \cdot \frac{L}{2r\pi n}$ = velocity of propagation along the spring axis. It will be seen that the first factor is the velocity of propagation of torsion in a straight rod; the second factor is the ratio between the polar moment of inertia of the spring wire and its

[3] This subject has been treated extensively, both theoretically and experimentally by Willy Marti, "Ventilfeder Schwingungen." Doctor's Thesis at the University of Zurich, Switzerland, 1935.

moment of inertia around the spring axis (ratio of torsional to bending moment); the third is the ratio of spring length to wire length.

$a_w = \frac{2r\pi n}{L} a_s = \sqrt{\frac{G}{\rho}} \cdot \sqrt{\frac{J}{Fr^2}} = 0.354 \frac{d}{r} \sqrt{\frac{G}{\rho}}$ = velocity of propagation along the wire. (For a steel spring with a d/r ratio of 0.15 and 0.30 the velocity of propagation along the wire will be: 173 and 346 m. sec.$^{-1}$, i.e., 569 and 1135 ft. sec.$^{-1}$ respectively.)

According to the law of momentum:

$$\Delta P \Delta t = Q a_s \Delta t \Delta v.$$

Substituting: $\Delta P = \frac{\Delta M}{r} = \frac{J}{r} \frac{\Delta \tau}{d/2}$, and also the above found values for Q, and a_s the equation

$$\frac{\Delta \tau}{\Delta v} = \frac{d}{2r} \frac{G}{a_w} = \text{constant}$$

is obtained, expressing the relationship between the change of velocity and the corresponding change of stress. Generalizing the above results it can be written for any type of spring worked below the elastic limit:

$$\frac{\Delta s}{\Delta v} = \text{const.} = \tan \alpha,$$

in which equation s represents stress, strain, force or torque (as all these quantities are proportional as long as the stress is below the elastic limit) and v represents velocity (rectilinear or angular) of a spring element. The constant can be calculated for any given case on the basis of the above examples and can be expressed as the tangent of the angle α which the directrix forms with the v-axis in the $v - s$ diagram.

SOME PROPERTIES OF THE STEREOGRAMS.

It was shown before (Fig. 6) that:

$$\frac{\partial u}{\partial t} = v \qquad \text{and} \qquad \frac{\partial u}{\partial x} :: s,$$

from which it follows that:

$$\left(\frac{\partial^2 u}{\partial t \partial x}\right) = \frac{\partial v}{\partial x} :: \frac{\partial s}{\partial t}.$$

Furthermore, it can be derived that:

$$\frac{\partial v}{\partial t} :: \frac{\partial s}{\partial x}.$$

In virtue of these relationships, if, for a pair of t, x values in the velocity-stereogram

$$v = f(x) = \text{const} \left(\text{i.e.,} \frac{\partial v}{\partial x} = 0\right),$$

then, for the same pair of t, x values in the stress-stereogram it will be:

$$s = f(t) = \text{const} \left(\text{i.e.,} \frac{\partial s}{\partial t} = 0\right)$$

and vice versa.

This interrelationship is useful in checking the correctness of the construction of stereograms. (Cfr. Figs. 11, 12, 13, 14, 15, 16, and 17.)

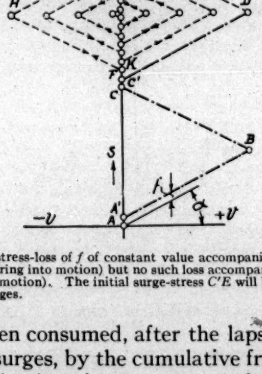
Effect of Friction and Damping.

A rigorous treatment of the influence of friction and damping is reserved for a future investigation. At the present the background of such influences will be briefly discussed.

Friction.—The $v - s$ diagram of a spring compression is shown in Fig. 25, assuming the lift-velocity constant, and the lift-duration T for which $2T_0 < T < 4T_0$. The effect of friction is that the stress-value must be greater than a certain f before motion can result (Point A). Therefore the stress corresponding to the lift-velocity (Point B) will be by the value of f higher than it would be without the presence of friction. The stoppage at the stationary end, however, is accomplished without such frictional loss (Point C). When the stoppage reaches the movable end another expenditure of f stress is necessary to restore the motion (Point C'). Thus point D will lie $2f$ higher than would be the case without friction. We have assumed a lift-duration less than $4T_0$, i.e., the movable end comes to a standstill during the second wave.

The surges therefore will start from the two points C' and E. The conversion of these stress-values into velocity value will take place, however, from points F and G instead of C' and E, the stress-difference being in both cases equivalent to the value of friction f. The resulting stress and velocity will be defined by the point H and the stress values corresponding to the stoppage of this surge will be again the points F and G. The following surge will start from points K and L corresponding to the friction-loss f. Thus the surges continue with ever-decreasing velocity-values until the total available surge-

FIG. 25.



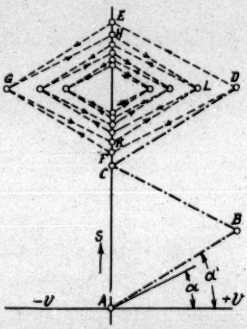
Effect of friction. A stress-loss of f of constant value accompanies each conversion of stress into velocity (setting the spring into motion) but no such loss accompanies the conversion of velocity into stress (stoppage of motion). The initial surge-stress $C'E$ will be consumed by the friction after a finite number of surges.

stress $C'E$ has been consumed, after the lapse of a finite number of remanent surges, by the cumulative frictional losses.

Damping.—The damping represents a loss of stress which is proportional to the velocity. Fig. 26 represents the $v - s$ diagram of a srping-compression at constant velocity and a lift-duration T for which $2T_0 < T < 4T_0$. The damping is represented by a directrix tan α' which has a steeper slope than the directrix tan α corresponding to the condition without damping loss. Conversions from stress into velocity take place according to the directrix tan α' (Points B and D) while conversions from velocity into stress (stoppage of a surge) take place according to the directrix tan α (Points C and E).

After the movable end comes to a standstill during the second wave the surge will start from the points E and F, and the resulting surge-velocity will be defined by point G (obtainable by the intersection of the two tan α' directrices drawn from points E and F). When the G surge is stopped at the two spring-ends the stresses H and K result (obtainable by the intersection of the two tan α directrices drawn from point G with the ordinate axis, $v = 0$). The next surge will be characterized by point L. Thus the surges continue with ever-

FIG. 26.



Effect of damping. A stress-loss proportional to the velocity accompanies each conversion of stress into velocity (setting the spring into motion directrix tan α') but no such loss accompanies the conversion of velocity into stress (stoppage of motion, directrix tan α). The initial surge-stress EF will be reduced by the damping forces to half the initial value after an infinite number of surges.

decreasing velocity-values until the half of the available surge-stress EF has been consumed by the cumulative damping losses, after the lapse of an infinite number of remanent surges.

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3. J. MAGG: Schwingungserscheinungen in zylindrischen Schraubenfedern und die Gesetze des Schlagens der Ventile. (Vibrations in cylindrical helical springs and the laws of valve-hammer.) Verhandlungen der Gesellschaft fuer die Befoerderung des Gewerbefleisses, No. 91 (1912), p. 480.

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Velocity of propagation of a disturbance in a spring. Phenomena in a spring surge. A history-diagram of the motion of an assumed spring is given.

4. L. F. G. SIMMONS: Investigation of the Fracture of Exhaust Springs. Reports and Memoranda of the Advisory Committee for Aeronautics (British). March 1916. London. H. M. Stationery Office. 10 p. 1 fig.

Fatigue due to dynamic stresses. Natural period of vibration determined by calculation and confirmed by experiment. In one set of experiments the spring was oscillated by means of a solenoid placed around the middle of the spring which itself was clamped in a vertical position between two supports and compressed to the desired amount. It was easily possible to excite and maintain the vibrations. In another set of experiments the oscillations were produced by means of a weight dropped on the end of the spring. The vibrations were magnified and recorded optically.

5. W. WEIBULL: De dynamiska egenskaperna hos spiralfjadrar. (The dynamic properties of helical springs.) 25 p. 19 figs. Stockholm. 1927. Svenska Bokhandelscentralen A.-B.

Formulas for the velocity of disturbance and for the strain in helical springs have been derived as functions of the dimension and of the material. Calculations have been made on the assumptions (1) that one end of the spring has an arbitrary velocity, and, (2) that a mass impacts against a free end of a spring with finite velocity. These have been verified experimentally by means of photographing on a revolving film drum the motions of the spring coils in an ingenious and successful manner.

6. A. SWAN AND L. G. SAVAGE. The Surging of Engine Valve-Springs. Engineering Research Special Report No. 10. His Majesty's Stationery Office. London 1928.

7. W. T. DONKIN AND H. H. CLARK: Electric Telemeter and Valve-Spring Surge, S. A. E. Jl., 24, March 1929, pp. 315–325. 20 figs.

A carbon-pile type resistance unit in connection with an oscillograph was used for measuring the forces at the end of the spring, when this latter is subjected to periodic compression. The experimental set-up is described in detail and a large number of experimental oscillograms are given.

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A brief and lucid explanation of spring surges and the dynamic, high-frequency stresses caused thereby. Comparison of test results on alloy steel and carbon steel springs.

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A thorough analytical treatment of spring surges; velocity of propagation; relationship between the local compressor and speed of wire movement.

11. E. LEHR: Schwingungen in Ventilfedern. (Vibrations in Valve Springs.) Z. d. V. D. I., 77, No. 12, 6 Mai 1933, pp. 457–462. 14 figs.

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12. F. NIXON: The Design of Valve-Springs. Aircraft Engineering, Vol. V, Sept. 1933, pp. 193–196.

Brief discussion of surge; methods of reducing surge; valve-spring material; working stresses; design of valve-springs; charts, tables, examples; bibliography.

13. K. PFEIFFER: New Developments in Valve Springs for Gas Engines. Paper read before the Pittsburgh Section of the S. A. E. 1933. Unpublished manuscript.

Deleterious influence of surges is due mainly to the increasing of the number of stress cycles through which the spring must work. High spring rate with low dynamic stresses, versus low spring rate with high dynamic stresses. Various materials tried. Damping methods.

14. T. G. STOUDT: Investigation of Surge Phenomena in Tension Springs. Master's Thesis. The Pennsylvania State College. 1934. (Mimeographed copy.)

The motion of various coils of a long spring (used in textile machinery) was investigated with an Edgerton stroboscope. Effect of frequency of impressed motion, and of initial spring tension was studied.

15. WILLY MARTI: Ventilfeder-Schwingungen. (Vibrations in Valve-Springs.) Dissertation T. H. Zurich, Switzerland. 1935. 21 p. 33 figs. Publ. Buchdruckerei Winterthur vorm. G. Binkert A.-G.

An analytical and experimental investigation of spring surges; dynamic stresses; vibration of spring after a single lift-motion, as a function of speed; influence of cam-curve; criterion for resonance; influence of damping, of initial spring-tension, of backlash in the roller. The forces at the two ends of the springs were determined by means of piezo-electric quartz-elements and an oscillograph.

STRESSES AND DEFORMATIONS IN PIPE FLANGES SUBJECTED TO CREEP AT HIGH TEMPERATURES.

BY

JOSEPH MARIN,

Assistant Professor of Engineering Materials, Rutgers University, New Brunswick, New Jersey.

ABSTRACT.

Various solutions have been made for determining the stresses in pipe flanges using the theory of elasticity (1). There are many cases, however, of pipe flanges which are subjected to stresses and at the same time a high temperature such that creep occurs. This paper gives an analysis of the stresses and deformations produced in a circular ring of rectangular cross section subjected to twisting couples uniformly distributed along its center line. Such a solution will also give an approximate analysis of the pipe flange. This approximation is justified in view of the complexity of the problem and the uncertainties still present in the fundamental creep-stress relation for metals. In the solution of this problem a deflection theory is also developed for straight beams subjected to bending accompanied by creep.

INTRODUCTION.

There are pipe flanges which are subjected to stresses and at the same time to a high temperature. Under such conditions the creep deformation increases with time. It is of importance to know the value of this deformation as well as the resulting stress distribution. An analysis of the deformations and stresses in bolts connecting flanges has been made by Baumann (2), Bailey (3) and Soderberg (4). This paper gives an approximate analysis of the stresses and deformations produced in the flange part of temperature joints. In the solution of this problem the case of pure bending of beams will first be considered. With this as basis, the stresses and deformations in a pipe flange can be determined.

PURE BENDING OF BEAMS.

In the following discussion of beams subjected to pure bending and creep, a prismatical beam is considered with a plane of symmetry in which the bending forces are applied. The beam is submitted to the action of couples lying in the plane of symmetry and applied at the ends of the beam

(Fig. 1). To determine the stress distribution under such conditions two assumptions will be made:

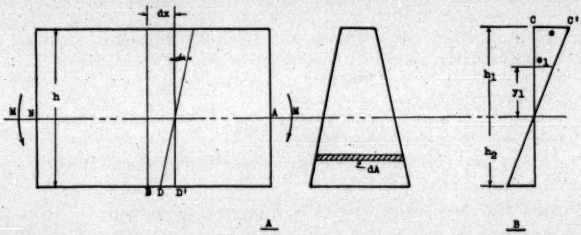
(i) That a transverse cross section of the beam originally plane and normal to the center line of the member remains plane after bending.

(ii) That for any fibre the relation between the creep rate and stress is the same as for simple tension and is

$$C = A\sigma^n \qquad (1)$$

where C = a constant creep rate or plastic strain per unit length per unit time.
σ = Unit stress.
A and n = Experimental constants for the material.

FIG. 1.



The above assumptions have experimental support in tests made on lead beams by MacCullough (5) and Tapsell (6). Although equation (1) needs further experimental proof, a study of data shows that it is as satisfactory as the semi log relation $\sigma = D \log C + F$, where D and F are experimental constants. A more complicated expression but one which gives the best agreement with test results has been presented by Soderberg (4).

In addition to the above assumptions, it is necessary that the two conditions for static equilibrium be satisfied, namely,

(i) That the summation of stresses perpendicular to any cross section of the beam and at right angles to the longitudinal axis be zero. That is $\Sigma F = 0$.

(ii) That the internal resisting moment due to these stresses be equal to the external applied moment. That is

$\Sigma M = M$. With the above assumptions and conditions of equilibrium the stress distribution can be determined. For this purpose let e, C, and σ = the creep deformation, creep rate and stress respectively, for the outer fibre, and e_1, C_1 and σ_1 = the corresponding value for any fiber distance y_1 from the neutral axis. The moment M produces stresses which vary over the cross section such that there is a line, the neutral axis, where the stress is zero. For plane sections to remain plane (assumption (i))

$$\frac{e_1}{e} = \frac{y_1}{h_1}. \qquad (a)$$

Experiments by MacCullough (5) and Tapsell (6) showed that the creep rate becomes constant and a minimum soon after the application of the load. Then

$$\frac{C}{C_1} = \frac{e}{e_1}. \qquad (b)$$

Then from (a) and (b) the creep rates are proportional to the distances from the neutral axis or

$$\frac{C}{C_1} = \frac{y_1}{h_1}. \qquad (c)$$

The variation of stress over the cross section is now obtained by combining equation (a) with assumption (ii). By assumption (ii)

$$C = A\sigma^n \qquad \text{and} \qquad C_1 = A\sigma^n \qquad (d)$$

Placing values of C and C_1 from (d) in (c) the distribution of stress is defined by

$$\frac{\sigma}{\sigma_1} = \left(\frac{h_1}{y_1}\right)^{1/n}. \qquad (e)$$

This relation reduces to the one for the case of elasticity when $n = 1$. The position of the neutral axis is defined by the condition of equilibrium, namely, that the summation of the stresses for any cross section must be equal to zero or

$$\int_{h_2}^{h_1} \sigma_1 da = 0, \qquad (f)$$

where da is an element of area of the cross section at a distance y_1 from the neutral axis. For a *rectangular cross* section $da = bdy$. Then from (e) and (f)

$$b\sigma\left(\frac{1}{h_1}\right)^{1/n}\int_{h_2}^{h_1}(y_1)^{1/n}dy_1 = 0. \qquad (g)$$

It is assumed in writing (g) that the creep laws governing tension and compression are the same. For equation (g) to be satisfied, the integral must be zero. Thus for a rectangular cross section the neutral axis and centroidal axis coincide and are at mid-depth. To determine the actual stress distribution the second condition of equilibrium will be used, namely, that the external moment M equals the resisting moment or

$$M = \int_{-h/2}^{h/2}\sigma_1 y_1 da. \qquad (h)$$

Placing the value of σ_1 from (e) in (h) the integral in (h) can be evaluated. This gives the stress σ at the outer fiber as

$$\sigma = \frac{Mh}{I}\left(\frac{2n+1}{6n}\right), \qquad (2a)$$

where I = the moment of inertia of the cross section about the neutral axis. Then for any fiber the stress is from $(2a)$ and (e)

$$\sigma_1 = \frac{M(2y_1)^{1/n}}{I(h)^{(1-n/n)}}\left(\frac{2n+1}{6n}\right). \qquad (2b)$$

Equation $(2b)$ completely determines the stress distribution in terms of the load, dimensions and the material constant n. It is convenient to represent the stress distribution graphically by comparing it with the elastic case. For the latter, the stress on the outer fiber is

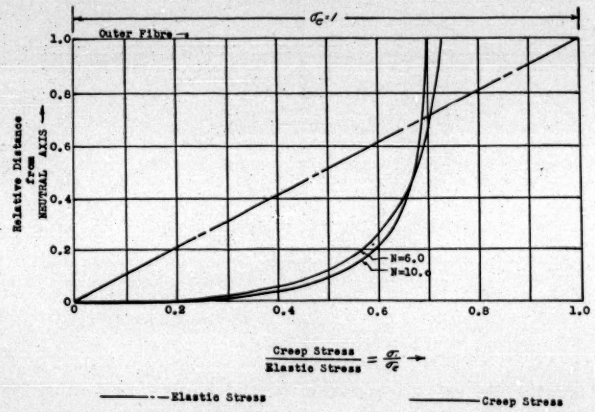
$$\sigma_e = \frac{Mh}{2I}. \qquad (i)$$

Then the creep stress σ_1 in terms of σ_e is from $(2b)$ and (i)

$$\sigma_1 = \sigma_e\left[\left(\frac{2y_1}{h}\right)^{1/n}\left(\frac{2n+1}{3n}\right)\right]. \qquad (j)$$

The variation in stress σ_1 is shown in Fig. 2 for a value of $\sigma_e = 1$. The stress distribution is shown for values of n representing different carbon steels. The stress distribution is such that it is more favorable than in the elastic case. It is also of interest to note that the variation in the value of n makes little difference in the value of the stress. The above theory is essentially that given by Tapsell (6) and Bailey (3). With this as a basis the deflection of beams subjected to creep

FIG. 2.



can be formulated as well as the analysis of pipe flanges. To determine the deflection of beams in the case of creep assumptions (i) and (ii) will be used. Then the section CD deforms relative to AB such that the new position of CD is $C'D'$ (Fig. 3) and the unit deformations at distances h_1 and y_1 are respectively

$$e = \frac{h_1}{f_1}, \qquad e_1 = \frac{y_1}{f_1} = C_1 t, \tag{k}$$

where f_1 = the curvature due to creep and t = the time.

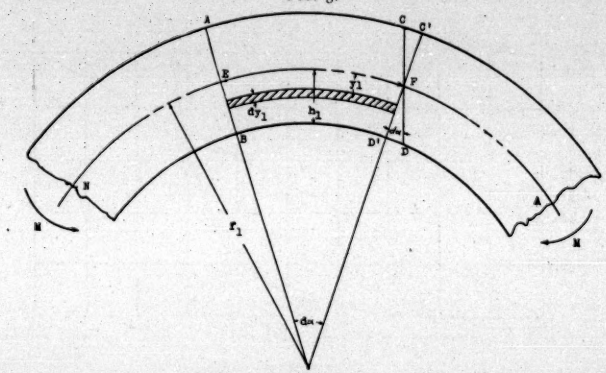
Placing value of C_1 from (d) in (k) the stress σ_1 is

$$\sigma_1 = \left(\frac{y_1}{tf_1A}\right)^{1/n}. \qquad (l)$$

For equilibrium the internal moment equals the applied moment M or

$$M = \int y_1\sigma_1 da = \left(\frac{1}{Atf_1}\right)^{1/n} \int (y_1)^{(1/n)+1} da. \qquad (m)$$

FIG. 3.



To integrate (m) the position of the neutral axis must be known. This is defined by equation (f), the condition of equilibrium that the summation of the stresses equals zero. Equations (m) and (f) then completely define the curvature for a moment M at the time t. For a *rectangular section* from (m) and (f)

$$M = \left(\frac{1}{Atf_1}\right)^{1/n} \frac{2b\left(\frac{h}{2}\right)^{(1/n)+2}}{2+\frac{1}{n}}$$

or

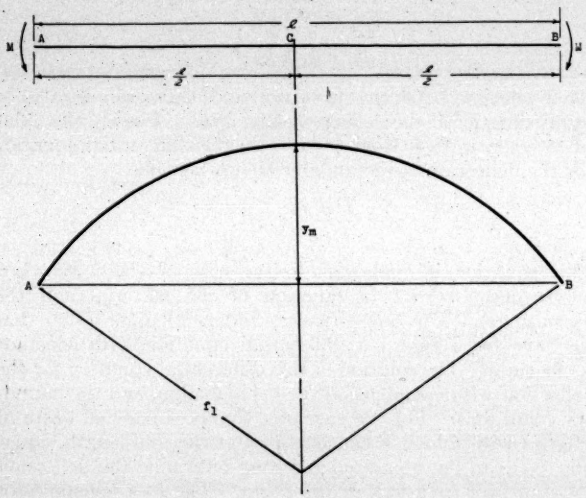
$$\frac{D}{t}\frac{1}{f_1} = M^n, \qquad (3a)$$

where

$$D = \frac{\mathrm{I}}{A} \frac{(2b)^n \left(\frac{h}{2}\right)^{2n+1}}{\left(2 + \frac{\mathrm{I}}{n}\right)^n}$$

for a rectangular cross section. To determine the deflection from (3a) it is necessary to know the deflection in terms of

FIG. 4.



the curvature f_1. For this purpose, consider the beam of length l subjected to a moment M (Fig. 4). By symmetry the maximum deflection is at the mid point C and its value in terms of the curvature and length l is $y_m = \frac{l^2}{8f_1}$. Then from (3a) in terms of the moment

$$y_m = \frac{t}{D} \frac{l^2}{B} M^n. \qquad (3b)$$

In this way the deflection due to creep is completely defined for a moment M at a time t.

In the usual case of bending in beams there is produced not a pure bending stress but a combination of bending and transverse shear. In such cases, the deflection can be determined if it is assumed, as in the case of elasticity, that the dimensions of the beam are such that deflections due to shear stresses are negligible. Equation (3a) can be used to determine deflections in such beams by replacing the curvature f_1 in terms of the deflection y. Referring to Fig. 3.

$$\frac{1}{f_1} = \frac{d\alpha}{dx} = \frac{d}{dx}\left(\frac{dy}{dx}\right) = \frac{d^2y}{dx^2}. \qquad (n)$$

This relation between curvature and deflection is a good approximation if the deflections are small. Placing the value of the curvature f_1 from (n) in (3a) the differential equation for the deflection of rectangular beams becomes

$$\frac{D}{t}\frac{d^2y}{dx^2} = M^n. \qquad (3c)$$

This equation is analogous to the case of elasticity when $n = 1$ and $D = EI$ (a function of the material and the dimensions). The quantity D is independent of M so that we have for a time t a differential equation with constant coefficients. The solution of this differential equation for the deflection y is dependent on the beam loading and the boundary conditions. For the case of a simply supported beam of length l with a load P concentrated at the mid-length, equation (3c) can be integrated twice to determine the deflection equations for each half of the beam. The four constants of integration obtained are evaluated from the boundary conditions. By this procedure the deflection at a distance x from one end reduces to

$$y = \left[\left(\frac{P}{2}\right)^n \frac{t}{d}\right]\left[\frac{x^{n+2}}{(n+1)(n+2)}\frac{\left(\frac{l}{2}\right)^{n+1}}{n+1}x\right]$$

and the maximum deflection is

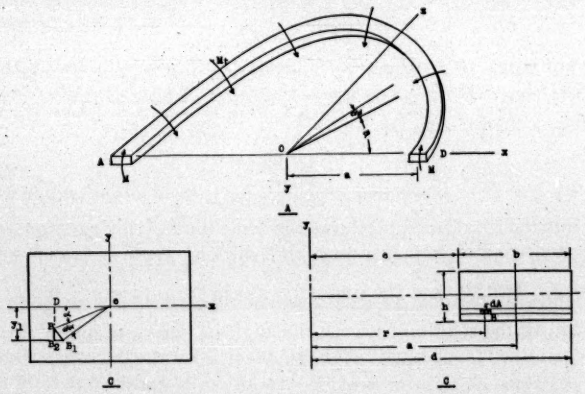
$$y_m = P^n \frac{t}{D}\left(\frac{1}{n+2}\right)\frac{l^{n+2}}{2^{2(n+1)}}. \qquad (3d)$$

At the end of 10 years and for $\frac{h}{l} = \frac{1}{20}$ the magnitude of this deflection is from 5 to 10 per cent. of the elastic deflection. These values refer to a 0.3 per cent. carbon steel at 400° C. In the same way, deflections can be obtained for beams with various loadings and boundary conditions. A method of graphical integrations can be used for the case of curved beams.

CIRCULAR RING SUBJECTED TO TWISTING COUPLES UNIFORMLY DISTRIBUTED ALONG ITS CENTER LINE.

There have been several analyses made for determining the elastic stresses in pipe flanges (1). An analysis in the case of creep is complicated by a more complex stress-strain relation. As a preliminary solution, therefore, the pipe flange

FIG. 5.



will be considered as a circular ring of rectangular cross section subjected to twisting couples uniformly distributed along its center line (Fig. 5*a*). It is realized that such an approximation can only give an estimate of the stresses and deformations which actually occur. It is justified, however,

by the fact that a basic creep-stress relation has not been definitely established.

To determine the stresses produced in the assumed flange, consider a free body of half the ring (Fig. 5*a*). For equilibrium there are bending moments at A and D equal to M such that

$$M = \frac{1}{2}\int_0^{\pi} M_t a d\varphi \sin \varphi = M_t a, \qquad (o)$$

where a = the radius of the center line and M_t = the twisting couple per unit length of the center line. To determine the stresses due to the moment M it will be assumed that the rotation θ_1 is small and that the assumptions used for pure bending of beams can be used for this problem. Due to the rotation θ_1 a point B in the cross section will move to B_1 (Fig. 5*b*). The increase in the radius on which B is located is

$$\overline{B_1B_2} = \theta_1 y_1. \qquad (p)$$

This value is obtained by considering the similar triangles DBC and BB_1B_2. The unit elongation of fiber B due to the displacement $\overline{B_1B_2}$ is

$$e_1 = \frac{\theta_1 y_1}{r}. \qquad (q)$$

Thus the rotation θ_1 produces the same kind of deformation as in the case of pure bending and the above analysis can be used. In this case the quantity $\frac{\theta_1 y_1}{r}$ in (q) replaces $\frac{y_1}{f_1}$ in (k). That is, the relation between the angle of twist and moment is determined from equation (n) by placing for the curvature the value $\frac{r}{\theta_1}$. Then

$$M = \left(\frac{\theta_1}{At}\right)^{1/n} \int \frac{(y_1)^{(1/n)+1}}{(r)^{1/n}} da, \qquad (r)$$

where θ_1 is the increase in the angle of twist due to creep beyond the initial condition. Placing $M = M_t a$ and $da = dydr$

in (r) and solving for θ_1,

$$\theta_1 = \left[\frac{M_t a (2)^{1+(1/n)} \left(1 - \frac{1}{n}\right)\left(2 + \frac{1}{n}\right)}{(d^{1-(1/n)} - c^{1-(1/n)}) h^{2+(1/n)}} \right]^n At. \qquad (4a)$$

By equation $(4a)$ the angle of twist produced by creep for a time t is completely defined.

To determine the stress distribution, the relation between creep and stress for pure bending can be used by replacing $e_1 = \frac{y_1}{f_1}$ (equation (k)) by $e_1 = \frac{\theta_1 y_1}{r}$ (equation (q)) in equation (1). This substitution gives a relation between the creep deformation and stress, namely

$$e_1 = \frac{\theta_1 y_1}{r} = tA(\sigma_1)^n. \qquad (s)$$

Eliminating the angle θ_1 from equations (s) and $(4a)$ the stress σ_1 for a point B is

$$\sigma_1 = \left(\frac{y_1}{r}\right)^{1/n} M_t \left[\frac{a}{(d^{1-(1/n)} - c^{1-(1/n)}) h^{2+(1/n)}} \right] \times \left[2^{1+(1/n)} \left(1 - \frac{1}{n}\right)\left(2 + \frac{1}{n}\right) \right]. \qquad (4b)$$

The maximum value of σ_1 is by inspection for $y_1 = \frac{h}{2}$, $r = c$, or

$$\sigma_m = \left(\frac{h}{2c}\right)^{1/n} M_t \left[\frac{a}{(d^{1-(1/n)} - c^{1-(1/n)}) h^{2+(1/n)}} \right] \times \left[2^{1+(1/n)} \left(1 - \frac{1}{n}\right)\left(2 + \frac{1}{n}\right) \right]. \qquad (4c)$$

In this way the stress is completely defined for a given material and known dimensions. It is of interest to compare this value of stress with that given by elasticity. The value of the maximum stress in elastic case as given by Timoshenko (7) is

$$\sigma_e = \frac{Mh}{2I} = \frac{6aM_t}{h^2 b}. \qquad (t)$$

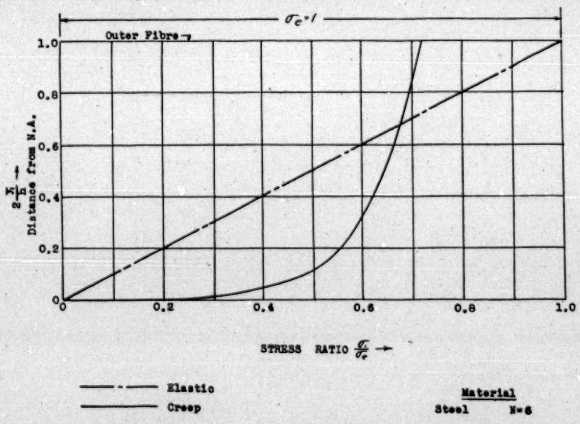
The relation between this stress and the creep stress is from

(4*b*) and (*t*)

$$\sigma_1 = \sigma_e \left[(y_1)^{1/n} \left\{ \frac{b}{6(a)^{1/n}} \right\} \times \left\{ \frac{2^{1+(1/n)} \left(1 - \frac{1}{n}\right)\left(2 + \frac{1}{n}\right)}{\{d^{1-(1/n)} - c^{1-(1/n)}\} h^{1/n}} \right\} \right]. \quad (4d)$$

To represent the variation in the stress σ_1 with y_1, it is necessary to know the dimensions and the material constant n. For a medium carbon steel and for usual operating temperatures an average value of n is about 6. Considering a ring with $d = 6\frac{1}{4}''$, $c = 3\frac{5}{16}''$, $h = 1\frac{7}{16}''$ the variation in stress is represented in Fig. 6 for the inner edge of the ring where

FIG. 6.



(*r*) = *a*. As in the case of pure bending the variation in stress is more favorable than in the case of elasticity.

ACKNOWLEDGMENT.

The writer wishes to acknowledge the generous help of Professor S. Timoshenko in the writing of this paper.

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Chinese Relativity.—The Chinese coolie has a method of treating DISTANCE which is quite scientific. The coolie will think of DISTANCE in terms of EFFORT so that he may claim that the distance up a hill is 5 li (say) while the distance down the same hill is only 3 li. Now a somewhat similar idea exists in post-Einstein physics in which a straight line may be defined as "the path of least effort in vacuo," but if we tie this to the other definition then we can say; "The shortest distance between any two points is the path of least effort between those points," and so the coolie is a relativist because surely it takes less effort to walk down rather than up a hill. In physics this correlation with EFFORT appears also in ENTROPY and as LEAST WORK in mechanics.

STRAIGHTNESS for all observers, is the path of light in vacuo where they are, since that is their local path of least effort. Nevertheless the eclipse of the sun shows that two paths of light (two locally straight lines) may pass between the same two points and yet enclose an area. I have a simple instrument with which the eclipse phenomenon (outward displacement of star images) can be duplicated easily any time. Of course this does not mean that space is non-Euclidean; it only means that paths of light over astronomical distances are not Euclidean straight lines, since if you use those paths as lines, the figures you draw will not check Euclid. I put it to you that if you can once see that this mysterious distortion about which so much has been written, is not a quality of space itself, but a quality of paths of light IN space, then the meaning of Einstein's great structure will not confuse you. This idea of the relativity of straightness appears in social life, but we call it "rights" (or wrongs) and we fight over it. You see, just as gravitational fields determine straightness in physics, so also our early training and our personal environment determine our local standard of "rights."

A. A. MERRILL.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

SPECTROGRAPHIC DETECTION OF RARE EARTHS IN PLANTS.

The spectrograph is being applied to an ever-increasing extent in both the qualitative and quantitative analysis of materials. This instrument, which identifies the chemical elements by light emitted under suitable excitation conditions, is especially valuable in the examination of complex materials for which chemical analysis may be impractical. An interesting example of the value of spectrographic analysis was the recent examination by Bourdon F. Scribner of a material separated from plant ash.

This substance was obtained from hickory leaves in the course of the investigation of the chemical composition of plant materials, undertaken by the Bureau of Chemistry and Soils. Since the substance could not readily be identified by chemical means, it was submitted to the National Bureau of Standards with a request for spectrographic test. With the aid of a grating spectrograph, Mr. Scribner made an examination for 64 chemical elements, and was able to identify the sample as a mixture of rare earths, nearly free of common elements.

The rare earths constitute a group of 13 transition elements lying between lanthanum and hafnium in the periodic system and, in addition, scandium, yttrium, and lanthanum, which have similar properties. The rare-earths are found as mixtures in small amounts, but widely distributed in the earth's crust. They have been found present in plant and animal tissues but usually in very small quantities. The rare-earth concentrate from the hickory leaves, however, amounted to 0.2 per cent. of the dry weight of the leaf, equaling the concentration of SiO_2 in the sample and exceeding the MnO which is 0.15 per cent. and Na_2O which is 0.02 per cent. The source of the rare-earths in this case was no doubt, the pegmatite vein in which the sample was growing.

* Communicated by the Director.

Because of the possible influence of the rare earths on the plant, it appeared worth while to examine further into the occurrence of these elements. Several samples of hickory leaves from different localities, birch and sweet-leaf leaves, and of black raspberries were subjected to chemical treatment at the Bureau of Chemistry and Soils to concentrate the rare earths, after which the concentrates were examined at the Bureau. Rare earths elements were found in every concentrate tested, the number varying from 4 to 13 elements.

The following elements were detected: Scandium, yttrium, lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, erbium, and ytterbium. The remaining three rare earths, holmium, thullium, and lutecium were not detected in the samples.

In view of the effect of certain rare constituents, such as boron, on plant growth, the possibility of modification of growth characteristics by the rare earths should not be overlooked. It is planned, therefore, to make a further investigation of the subject.

TURBULENCE OF WIND STREAMS.

Every one is familiar with the fact that the wind seldom blows with uniform and steady speed. Usually the wind is gusty; its speed rises and falls in an irregular manner. This behavior is characteristic of the flow of air in nearly all cases of technical interest, in ventilating ducts, around the blades of fans and propellers, and near the surfaces of aircraft, and so forth. The technician speaks of such a flow as a turbulent flow, considering the actual motion as made up of a steady motion on which a turbulence is superposed.

About 15 years ago the Bureau, in coöperation and with the financial assistance of the National Advisory Committee for Aeronautics, began a study of the fundamental aspects of turbulence in connection with the practical problem of standardizing methods of making tests of aircraft models in wind tunnels. Wind tunnels are designed to give as steady an air flow as possible, so as to reproduce the same relative motion between model and air as between an aircraft in flight and the surrounding air. Some turbulence is always present. In many cases the flow around the model and hence the forces

acting on it depend on the amount and nature of this turbulence.

HEATS OF COMBUSTION OF COKES AND GRAPHITES.

The heats of combustion of 30 samples of anthracite cokes have been determined by Phillip H. Dewey and D. R. Harper, 3rd. These cokes were of known different temperatures of preparation (900° to 1300° C.), and had hydrogen contents from 0.08 to 0.78 per cent., and adsorptive capacities ranging from 0.13 to 37.5 ml. gaseous CO_2 per gram of solid carbon, so that the effect of these properties on the heat content of the materials could be studied. As shown in RP1139 in the October *Journal of Research*, data were also obtained on the heats of combustion of two samples of pure ash-free artificial graphite and four different samples of natural graphite.

HEATS OF COMBUSTION OF DIAMOND AND GRAPHITE.

Data on the heats of combustion of the various forms of carbon are of considerable interest in thermochemistry, because carbon is present in all organic compounds, and a value for the heat of combustion of some form of carbon must be used in calculating the heats of formation of practically all such compounds. Most previous measurements of heats of combustion of the various forms of carbon were made some time ago, and the results obtained by various experimenters are not in satisfactory agreement. Some of the data, for example, indicated that graphite was not a definite, reproducible substance, but that its heat of combustion varied somewhat, depending upon the treatment to which the graphite had been subjected. Since these data were obtained, some improvements have been made in the technique of heat of combustion measurements and in methods of interpreting the data of such experiments. New work on the heats of combustion of the various forms of carbon, therefore, appeared to be justified.

A project described in the October *Journal of Research* (RP1140), was part of a joint investigation undertaken by the Bureau and the Coal Research Laboratory of the Carnegie Institute of Technology. The Bureau's work, which was car-

ried out by Ralph S. Jessup, included measurements of the heats of combustion of two natural graphites, one artificial graphite, and two samples of powdered diamond. It has been found that when the graphites were purified the heats of combustion of the three samples were the same within 0.02 per cent., which is within the uncertainty of the measurements. The results obtained by Mr. Jessup are in practically perfect agreement with those obtained by the Coal Research Laboratory. The results obtained by the two institutions show that graphite is a definite, reproducible substance, at least so far as its heat of combustion is concerned.

The results on the diamond samples were not quite so satisfactory, since the values obtained for the heats of combustion of the two samples differed by 0.12 per cent. This difference is several times the uncertainty of the value for either sample. One of the samples of diamond was much more finely powdered than the other, and the difference in the observed heats of combustion is in the direction to be expected from the relative sizes of the particles, but is greater in magnitude than was predicted. It may be that the effect of particle size has been underestimated.

CRUSHING RESISTANCE OF ENAMELS.

The resistance of enamels to mechanical wear may be considered as the resultant of two components, namely: (1) The resistance of the surface layer to abrasion, and (2) The resistance of the underlying enamel structure to crushing. The first of these types of wear occurs, for example, in scrubbing an enamel surface with a cleansing powder. (The chemical action of such powders is not under consideration in the present discussion.) Both types of wear may be involved in the scratching of an enamel with a gouging tool, rolling cutter or other implement of similar action, since the surface is penetrated and also the understructure is crushed or torn. Since the resistance of enamels to these types of wear is not necessarily proportional, it is essential to test for each one separately in order to deal effectively with the causes and remedies for the respective types of wear.

The test for resistance to surface abrasion, which was referred to in *Technical News Bulletin* 247 (November, 1937) has

been adopted as a tentative standard by the Procelain Enamel Institute, after experimental work in which members of the Institute coöperated.

A test for crushing resistance of enamels has recently been studied at the Bureau by W. N. Harrison and L. Shartsis, and wide differences between different enamels have been found. The test consists essentially of rolling a small ball bearing, under various known loads, on the surface of the enamel, and observing the load required to gouge out a path in the enamel.

The use of a ball bearing, which may be replaced as often as necessary, eliminates the difficulty which has been found in obtaining identical gouging tools, and maintaining them in a given shape, even diamonds having been found to wear significantly. The difficulty of determining the end point, that is the load at which gouging occurs, is also reduced by the use of a ball bearing, since its path in the enamel has been found to be sufficiently broad, when it occurs at all, to be readily distinguished.

As the loads are increased beyond that at which crushing begins, greater percentages of the total path of the ball are gouged out. By arbitrarily establishing a given percentage as the end point, comparable results can be obtained. For close determination of this percentage, a mocrometer microscope is used.

By means of this test, definite differences in the crushing resistance of different areas on one 4 × 6 inch specimen were found. Also, different enamels have required loads varying from less than 20 to more than 100 pounds to cause crushing.

WEAR RESISTANCE OF CONCRETE FLOORS.

This Bureau has recently investigated the wear resistance of cement mortars and concretes of the type used for flooring. Wear was produced by rotating steel disks moving in a circular path on 23 by 27 by 1 inch slabs of mortars and concretes, varying from a 1 : 2 mortar mix to a 1 : 3 : 6 concrete mix. An abrasive between the disks and the slabs was supplied by an automatic feed. The actual depth of wear was observed with a specially designed optical gage. The effects of different cements, cement-water ratios, troweling procedures,

dust coats, curing conditions, metallic hardeners and liquid hardeners were studied.

Large differences in wear resistance were found for such factors as time of troweling and length of damp curing period, delayed troweling and longer damp curing as a rule increasing the resistance to wear. Mixes having the same cement-water ratio, but different proportions of cement, sand, and aggregate varied widely in their wear resistance. For example, a mix of 1 part cement to 2 parts sand gave about twice the wear that was given by a mix of 1 part cement to 1½ parts sand and 2 parts coarse aggregate, although each mix had a cement water ratio of 2.26. The metallic hardeners were quite effective in reducing the wear, but the liquid hardeners were not materially effective in the mixes studied.

The details of the test procedures and complete results will be reported in a future number of the *Journal of Research*.

COMMERCIAL STANDARDS FOR DISINFECTANTS, DEODORANTS, AND GERMICIDES.

Several pamphlets of interest to housekeepers, not only in individual homes, but also in larger institutions such as hotels, schools, hospitals, theaters, and public buildings of all kinds, have just been issued under the titles: Liquid Hypochlorite Disinfectant, Deodorant and Germicide, Commercial Standard CS68–38; Pine Oil Disinfectant, CS69–38; Coal Tar Disinfectant (Emulsifying Type), CS70–38; Cresylic Disinfectants, CS71–38; and Household Insecticide (Liquid Spray Type), CS72–38.

These pamphlets comprise the nationally recognized standards of quality for their respective products, and cover the composition, physical and chemical properties, identification, methods of packing, and certification of quality.

The purpose of these Commercial Standards is to provide minimum specifications for quality, as a basis for understanding and voluntary guaranties between producers, distributors, and users, and to serve as foundations for confidence on the part of purchasers that the efficacy of the materials is what should be expected of disinfectants, deodorants, and germicides, manufactured in conformity with nationally-recognized specifications.

These pamphlets include brief histories of each project, the membership of the standing committees organized to review suggestions for revision to keep the standards abreast of progress, and lists of acceptors.

Copies of any of these pamphlets are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

The Determination of the Specific Surface of Powders.—The first part of a treatment on this subject is dealt with by P. C. CARMAN in the *Journal of the Society of Chemical Industry*, Vol. 57, No. 7. Many workers within recent years have paid attention to the study of fine particles, i.e., those formed by ordinary processes of comminution, and passing a 100 mesh sieve, with a lower size limit of about 0.1 micron. In particular, methods of determining particle size and size distribution in powder have been greatly elaborated. On the other hand, the evaluation of the specific surface of fine particles has been accorded little attention, although, in most cases, it is more important than particle size. For instance, coal is pulverized to present a large surface to combustion, cement is finely ground because the completeness and the rapidity of setting will increase with the specific surface, a silica particle in the lung will dissolve more readily as the specific surface is greater, and a fine powder used as a filler for plastics imparts strength largely by virtue of its large specific surface. Further, the theoretical work done in grinding must be related to the increase in specific surface. A new method is suggested for obtaining the specific surface of sands and fine powders which consists of measuring the permeability of a small sample to a liquid of known viscosity and, from this, to calculate the specific surface by the use of an equation. This equation has been tested systematically over a wide range of conditions, and may, therefore, be accepted with confidence. The new method is not affected in simplicity or accuracy if the powder contains mixed sizes of particles, and particles of irregular shape. Consequently it might well replace measurement of particle size distribution for routine work in an industrial laboratory.

R. H. O.

THE FRANKLIN INSTITUTE

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Studies of the Metabolism of the Strict Anaerobes (Genus Clostridium). I. Dehydrogenation Reactions by Suspensions of Cl. sporogenes.—WALTER KOCHOLATY AND J. C. HOOGERHEIDE. (*Biochemical Journal*, **32**: 437, 1938.) A great number of amino acids and biologically interesting compounds have been investigated as to their ability to act as hydrogen donators with washed suspensions of *Cl. sporogenes*. These investigations show that there are a great many factors which influence very markedly the results of dehydrogenation reactions when reducible dyes are used as hydrogen acceptors. The following are important factors: the age of the culture, the pH of the medium, the composition of the medium, and the pH at which the dehydrogenations were performed. Usually the activity towards different substrates decreases during continued incubation. Some substrates, however, are more rapidly dehydrogenated by older cultures. The pH curves for different substrates are completely different and the pH optima for dehydrogenation may vary greatly. This indicates that comparison of dehydrogenating potencies must be made with due regard to the pH at which they have been investigated. Marked changes in the pH curves for the different substrates were observed when the bacteria employed were cultivated at a more acid reaction. In general these curves show a shifting towards the acid side, indicating an adaption of the organism, so that these substrates could be attacked more easily at a low pH. These factors, related to the conditions under which the bacteria have been cultivated, indicate the ease with which the organisms adapt themselves to changes in their environment. Organisms grown in broth only are not identical with those grown in broth to which glucose has been added, as the latter have developed to a high degree the enzyme mechanism necessary to utilize glucose,

while this mechanism is rudimentary in organisms grown in broth alone. Repeated cultivation in a glucose-containing medium gradually develops the glucose-utilizing mechanism. The different behaviors of the dehydrogenases, acting on certain substrates, towards poisons such as HCN, As_2O_3, NaF, $CuSO_4$ are described.

Studies in the Metabolism of the Strict Anaerobes (Genus Clostridium). II. Reduction of Amino Acids with Gaseous Hydrogen by Suspensions of Cl. sporogenes.—J. C. HOOGERHEIDE AND W. KOCHOLATY. (*Biochemical Journal*, **32**: 949, June 1938.) It was found that gaseous hydrogen can be utilized in the metabolism of the strict anaerobes in a way that is comparable to the utilization of gaseous oxygen by the aerobic microörganisms.

Apparently the organism used (*Cl. sporogenes*) has the ability to activate gaseous hydrogen and to accomplish reductions which do not occur without such a bio-catalyzer. Proline, oxyproline, glycerin, ornithine, arginine, tryptophane, certain aldehydes and ketones and many other substrates to a lesser extent could be reduced with gaseous hydrogen, with the help of washed suspensions of *Cl. sporogenes*.

The chemical reactions of these reductions of the amino acids mentioned have been studied and evidence is given that each absorbs 1 molecule of H_2 per molecule of amino acid. In the case of proline and oxyproline the ring-bonds are opened and δ-amino-valeric acid formed from the former and the γ-hydroxy-compound from the latter. The other amino acids are reduced on the side of their NH_2 groups. NH_3 and the corresponding acids are formed.

This ability to utilize gaseous hydrogen was used as the basis of a method for the detection of substrates able to act as H-acceptors. It was found that several substrates not only were good H-donators but at the same time good H-acceptors. This makes it possible for the organism to accomplish a chemical reaction between 2 molecules of such a substrate in which one molecule is oxidized, the other reduced (e.g. tryptophane). These reactions are independent of the presence of H_2 and occur also as side reactions along with the H_2 uptake.

Serine, cystine, cysteine, methionine, pyruvic acid, glucose and to a lesser extent arginine, are actively fermented by washed suspensions of *Cl. sporogenes*. Glucose was the only substrate from which H_2 was evolved.

The bacteria have to be cultivated in the presence of glucose in order that the H_2-activating catalyst be present. This indicates that the enzyme reversibly activates the reaction: $2H \leftrightarrows H_2$.

Measurement of Radiofrequency Voltage in a Cyclotron.—W. E. DANFORTH AND M. B. SAMPSON. (*The Review of Scientific Instruments*, 9: 175, June 1938.) Three methods are described for determining the value of the high frequency voltage on cyclotron accelerating electrodes or "dees." Method I employs a device which is, in essence, a radio-frequency fluxmeter and by which the current in the conductors leading to the dees (and thence the voltage upon them) is determined. The value of this current to the dees is calculated from the induced current in a small test loop held near one of the said conductors. Knowing the current to the dees and the dee capacity the voltage can be computed. In method II the induced high frequency current flowing between the deflector electrode and ground is measured. To obtain a voltage value from the magnitude of this current one must first evaluate a coefficient of capacity and a coefficient of induction. The theoretical considerations involved as well as the practical procedure for doing this are fully discussed. Method III employs the well known device of charging a condenser through a diode rectifier, condenser and rectifier being connected in series between the two conductors whose alternating potential difference is to be measured. The charge acquired by the condenser is determined by measuring the leakage current in a high resistance connected across its terminals. Brief remarks concerning continuously reading control-room voltmeters, calibrated by any one of the above methods, are included.

Lead Poisoning in 1936 and Earlier Years.—FREDERICK L. HOFFMAN. (Monthly Labor Review of the Bureau of

Labor Statistics, United States Department of Labor, February 1938.) A marked decline in the occurrence of fatal lead poisoning has been observed in all countries. Although it would be desirable to have uniformity of procedure in methods of recording occupational and non-occupational lead poisoning deaths, comparisons are possible and it is observed that the incidence declined 60 per cent. in the United States between 1900 and 1936, 76 per cent. in England and Wales and 68 per cent. in Scotland, while similar declines are evident elsewhere. Decline in industrial lead poisoning is attributed to sanitary improvements in factory conditions, to better physique of the workers as a result of improved economic conditions with higher wages and shorter hours, and principally to the fact that Workmen's Compensation has transferred the responsibility for lead poisoning from the workman to the industry. There also has been progress in diagnosis of the disease. In 1935 there were 130 deaths from lead poisoning in the United States, of which 96 were strictly industrial in origin. The average age at death was 43, although twenty-eight non-occupational deaths were of boys and girls under fourteen years of age. Most deaths of children are due to sucking paint from toys or furniture. Twenty-one states, against sixteen a year ago, now compensate for industrial diseases. Information for these states bears out the decreasing incidence of lead poisoning in the United States. In New York, for example, compensation costs in 1935 were $141,379 while in 1936 they were $78,239. In Wisconsin, compensation costs were $8,380 in 1934 and $1,259 in 1935. International rates are not strictly comparable due to varying practices of including or excluding deaths due to non-occupational lead poisoning, and the inclusion of lead poisoning under general mineral poisoning. However, Canadian statistics show a stationary position, and rates for other countries show a low incidence except for the state of Queensland, Australia, where the rate is relatively high due to the alleged frequency of the disease in young children and the contaminated water supplies. The paper includes in addition physical and clinical statistics on lead workers in various plants throughout the United States.

The Cancer Problem.—FREDERICK L. HOFFMAN. (20th Edition "How to Live" by Irving Fisher and Haven Emerson, 354–361, 1938.) Cancer is now of prime importance because it has risen to second place in the causes of death and claims about 150,000 lives a year from some half million cases. Its onset is obscure and although the actual known duration is only about eighteen months, there is no way of knowing how long the cancer has been present. The cancer age is usually after forty but many younger persons are afflicted also, and the younger the patient the more serious the outlook. Any part of the human body is susceptible but the digestive system in males accounts for the largest mortality, while in females cancer of the genital organs takes the greatest toll, both regions being the site of inaccessible cancers, most difficult to diagnose and treat. Cancer of the digestive tract accounts for more than half of all cancer deaths. General symptoms, when recognizable, are persistent and rapid loss of weight, increased anemia, loss of appetite and gastric disturbances with, unfortunately, little or no pain at first. At present recognized treatment consists of surgery, x-ray and radium, or a combination of these. Cancer is considered cured after five years of non-recurrence, and the American College of Surgeons reports 24,440 five-year cures during the three years 1932–1934. Operation and radium are encouraging in cancer of the breast and cervix if they are recognized early enough, and the same holds true for many other sites, particularly cancer of the lip, 70 to 80 per cent. of which are curable in the early stage. Any abnormality in any part of the body, especially in persons over forty years of age, should receive prompt and competent medical attention. Although so little is known of the causes of malignant growths, it is obvious that the best insurance against the disease is a thorough physical examination yearly. All physical efforts in moderation, including moderation in eating habits, tend to keep the human organism in good condition. The biochemical aspects of the problem seem to offer the greatest hope for the future.

A New McDonald's Solution. — ELLICE MCDONALD. (*Surgery, Gynecology and Obstetrics*, **66**: 246, Feb. 1, 1938.)

Twenty-two years ago a new disinfectant solution was reported which came to be called McDonald's Solution.

Fourteen years ago a review of results which the solution had in preventing infection of the skin at the time of operation appeared, and at that time many thousands of cases were reported. Since the first report, more than a million operation cases have had the skin surface treated with the solution.

A better form of the solution has been devised and has been in use for 7 years, but only recently reported.

The new solution is

	Parts
Sodium ortho-phenyl-phenate	2
Sodium oleate	8
Acetone	400
Alcohol 95 ethyl	600

Directions are given for its use.

Studies on the Inhibition of Glycolysis by Glyceraldehyde. —ZELMA BAKER. (*Biochemical Journal*, **32**: 332, 1938.) Mendel (1929) found that the 3-carbon sugar, glyceraldehyde, almost completely stops the formation of lactic acid from glucose by slices of tumor tissues. This effect is observed even in very low concentrations (0.001 molar) and is of interest because of the close chemical relationship between glyceraldehyde and the normal metabolite, glucose. It has now been found that the effect is not specific to cancer. Tissues which normally metabolize glucose, and which produce lactic acid at a high rate (cancer, brain, testis and embryo), do not glycolyze, i.e., form lactic acid, in the presence of glyceraldehyde. On the other hand, tissues which attack glycogen primarily and which have low glycolytic power (liver, kidney), actually produce more lactic acid in the presence of glyceraldehyde than in its absence. These observations indicate that the mechanisms involved in lactic acid formation are dependent upon the type of tissue in question.

The inhibition of tumor glycolysis by glyceraldehyde is completely reversible. It is largely prevented by addition of pyruvic acid, phosphopyruvic acid, and phosphoglyceric acid. Lactic acid production from methylglyoxal by tumor tissue, or from starch by muscle extract, is not inhibited by glyceral-

dehyde. Other closely related aldehydes (glycolaldehyde, propionaldehyde) do not exert any anti-glycolytic action. The same is true for the isomeric triose, dihydroxyacetone.

An Ultracentrifugal Study of Gelatin.—EDWARD B. SANIGAR, LAURA E. KREJCI, AND ELMER O. KRAEMER. (*Journal of the American Chemical Society*, **60**: 757, April 1938.) A study of four different brands of commercial gelatins in phosphate buffer solution of pH 7.5 was made by means of the Svedberg oil-turbine ultracentrifuge, using the refractive index method for the determination of sedimentation constant. Two concentrations, approximately 0.4 per cent. and 2.0 per cent., were employed for each gelatin and, to reduce the effects of gelation, the centrifugations were carried out at 34–35°. Ultracentrifuge sedimentation diagrams for the concentrated and the dilute solutions are given, as well as graphs showing the relationship between apparent diffusion constant and time of centrifuging, and the relationship between sedimentation constant and intrinsic viscosity of the solution. The sedimentation constants of the gelatins in the 0.4 per cent. solutions were found to vary between 2.60 and 3.30 at 34° compared with 3.43, the value found by Krishnamurti and Svedberg for a gelatin solution of the same concentration and pH measured at 20°, and 3.55 the constant for egg albumin, a normal globular protein of molecular weight 43,000. The departure of the ratio ϕ/cV (where ϕ = hydrodynamic volume, c = concentration in grams per cc. and V = the partial specific volume of the gelatin) from unity indicated that even at 34° and in dilute solution gelatin did not behave like egg albumin, hemoglobin and other globular proteins, i.e., it is evidently not a compact, spherical, unsolvated molecule. The sedimentation constants for the 2.0 per cent. solutions were found to be from 29 to 52 per cent. (average 41 per cent.) greater than those for the dilute solutions. From the data available it was impossible to decide whether this increase was due to aggregation or whether it was only apparent and due to an over-correction for the effect of the viscosity of the concentrated solutions on the sedimentation constants. The sedimentation constants of the gelatins in the dilute solutions were found to increase regularly with increasing intrinsic

viscosity. For the concentrated solutions, where the corrections for viscosity were appreciably greater, this relationship was only observed after the values of the sedimentation constants had been adjusted for the progressive dilution below the boundary caused by centrifuging in a sector-shaped cell in a field of varying intensity. All the solutions were found to be heterogeneous to various degrees with respect to particle size. In view of this, and of the behavior of gelatin as a non-spherical particle, no molecular weights are offered for the gelatins.

An Improved Capillary Clamp.—HERBERT K. ALBER. (*Industrial and Engineering Chemistry*, Analytical Edition, **10**: 348, 1938.) A short note is presented on improvements of a holder used in microchemical work. The capillary clamp facilitates the support, on the microscope stage, of objects of varying diameters, from 10 mm. to 0.3 mm. and less, such as capillary tubings, glass tubes, fibers, and electrodes. It can be applied in the observation of colors for holding the coloriscopic capillaries, in the observation and manipulation of electrolytic deposits for supporting the needle electrodes, in the exact measurements of the bore of fine capillaries used in the various microtechniques, etc.

Microchemical Laboratory of the Biochemical Research Foundation of the Franklin Institute.—HERBERT K. ALBER AND JOSEF HARAND. (*Industrial and Engineering Chemistry*, Analytical Edition, **10**: 403, 1938.) At the request of the editors of *Industrial and Engineering Chemistry*, the paper of the same title, published in this journal, **224**, 729 (1937), has been rewritten and shortened to appear under the section "Modern Laboratories." Special emphasis has been laid on the description of equivalent equipment, of efficient distribution of apparatus, and of facilities not generally found in ordinary analytical laboratories. A few of the special features of this microchemical laboratory, such as the work bench for qualitative inorganic and organic microtechniques, the work bench for suction, filtration, and vacuum drying procedures, the titration table, the work bench with drawers for storing weighing vessels and corresponding tares, the set-up of the microchemical balances, are described more in detail.

The Identification of the Active Crystalline Substance from Liver which Protects Against Liver Damage Due to Chloroform or Carbon Tetrachloride; and a Study of Related Compounds.—R. C. NEALE AND H. C. WINTER. (*Journal of Pharmacology and Experimental Therapeutics*, **62**: 127, Feb. 1938.) A white crystalline material which exerts a protective action against fatty degeneration and necrosis of the liver accompanying chloroform or carbon tetrachloride poisoning was isolated from commercial porcine liver extract.

A study has been made of a number of compounds related to this purine to determine the relation of chemical structure to protective activity and possibly elucidate the mechanism involved. In the purine series nucleic acid, guanosine, guanine, and hypoxanthine have all shown moderate protective activity. Adenine and the methylated purines (theobromine, theophylline and caffeine) were too toxic in the amounts administered to be of interest as protective agents. Uric acid afforded only slight protective activity. Imidazole and histidine, representing the imidazole portion of the xanthine molecule, were inactive as protective agents. Uracil, representing the pyrimidine portion of the xanthine molecule, approached xanthine in its protection against fatty degeneration of the liver tissue but failed to prevent heavy round cell infiltration.

Photomicrographs were made of representative liver sections and the histopathologic conditions demonstrated were discussed.

In general, the compounds were administered subcutaneously in two equal doses, one 48 hours and the second 24 hours before administration of the anesthetic in the gas chamber. Insoluble compounds were given both in alkaline solution and in neutral suspensions. Male albino rats weighing from 80 to 120 grams and procured from the same colony were used in all experiments.

The Distribution of the Succinic Oxidase System in Animal Tissues.—K. A. C. ELLIOTT AND M. E. GREIG. (*Biochemical Journal*, **32**: 1407, 1938.) The oxidation of succinic acid to fumaric acid appears to be a central reaction in the processes of tissue respiration. The system responsible for

this oxidation is known to consist of a specific dehydrogenase which causes succinic acid to reduce cytochrome, and the reduced cytochrome is in turn reoxidised by molecular oxygen under the influence of indophenol oxidase, or cytochrome oxidase. The distribution of the system has been studied using fine suspensions of tissues. The complete system is extremely active in kidney, liver and heart. Brain, testis, skeletal muscle, lung, adrenals, and retina have moderate to low activity. Thymus, pancreas, spleen, and blood have practically no activity. Of cancer tissues, Philadelphia No. 1 sarcoma, Walker 256 carcinoma (usually) and certain spontaneous mammary carcinomata (rat) are inactive while Jensen sarcoma, Flexner-Jobling and one example of Walker 256 showed definite though low activity.

The tissues fall into the same order when the dehydrogenase alone is estimated by the rate of decolorization (reduction) of methylene blue in the absence of oxygen. The oxidation of succinate is slower when methylene blue replaces the oxygen-oxidase-cytochrome system.

The rate of oxidation of *p*-phenylene diamine is a measure of the activity of the indophenol oxidase-cytochrome system. The tissues fall roughly into the same order with respect to this activity.

In some tissues,—heart, lung, muscle, spleen and some tumors,—the amount of cytochrome present limits the rate of succinate oxidation. In these tissues the addition of cytochrome *c* increases the rate to a higher value. The oxidation of *p*-phenylene diamine by the indophenol oxidase occurs through the mediation of cytochrome. All tissues oxidise the diamine more rapidly when cytochrome is added and by using excess of cytochrome the full activity of the oxidase can be estimated. The oxidase activity corresponds to an oxygen uptake of 500 $mm.^3$ per mg. dry tissue per hour in heart, and it is, in all tissues, considerably higher than is necessary to account for the whole normal respiration. The presence of salts affects the oxidase activity markedly.

Blood catalyses the oxidation of *p*-phenylene diamine strongly, but by a different mechanism. The catalyst is a breakdown product of hæmoglobin.

STATED MONTHLY MEETING, OCTOBER 19, 1938.

The regular monthly meeting was called to order at 8:30 o'clock by Mr. Walton Forstall, Vice-President. He called upon the Secretary who presented the following statement concerning the additions to membership since the last report:

Honorary	14
Active	46
Associate	63
Student	150
Total	273

The additions to the Library during the Summer recess amounted to 2655 titles.

Attention was called to the continuance, during the present month, of the planetarium demonstration: "How Will the World End?", and that the subject for November would be: "Astronomy or Astrology."

Announcement was also made of the coming course of Christman lectures on the Dodge foundation, which will be given this season by Prof. Hugh S. Taylor, of Princeton. His subject will be "Chemistry for Young Citizens."

The Chairman then introduced Dr. W. F. G. Swann, Director of the Bartol Research Foundation, who delivered an address on Science and Human Affairs. The speaker compared the state of science today with that of 150 years ago. He pointed out the reasons for the periodic occurrence of situations in which discoveries seem to have come to an end. The position today with regard to future progress and the directions in which progress may be expected; how far science has increased the happiness of mankind; also the scientific method of thought and its potentialities for other fields, such as world affairs, were discussed.

At the close of the meeting a rising vote of thanks was extended to Dr. Swann for his illuminating talk.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 707 readers made use of the facilities during the twenty-five days of September.

RECENT ADDITIONS.

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HAMMER, BERNARD W. Dairy Bacteriology. Second Edition. 1938.

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DAY, LOUIS J. Standard Plumbing Details. 1938.
HAUF, HAROLD DANA. Design of Steel Buildings. Second Edition. 1938.

Astronomy.

BAKER, ROBERT H. Astronomy. Third Edition. 1938.
WATERFIELD, REGINALD L. A Hundred Years of Astronomy. 1938.

Aviation.

JORDANOFF, ASSEN. Through the Overcast: the Art of Instrument Flying. 1938.
PAGÉ, VICTOR W. Airplane Servicing Manual. 1938.
ROSENDAHL, Commander C. E. What About the Airship? 1938.
Royal Aeronautical Society. Handbook of Aeronautics. Volume 3. 1938.

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American Men of Science. Sixth Edition. 1938.
CHAUVOIS, LOUIS. D'Arsonval. 1937.
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SCOTT, J. F. Mathematical Work of John Wallis (1616–1703). 1938.
SHEPHERD, GRANT. The Silver Magnet. Fifty Years in a Mexican Silver Mine. 1938.
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Organic Syntheses. Volume 18. 1938.
REILLY, JOSEPH. Explosives, Matches and Fireworks. 1938.

Civil Engineering.

CRISWELL, H. Highway Spirals, Banking and Vertical Curves. 1937.

Dictionaries and Encyclopædias.

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BOOK REVIEWS.

SUBMARINE, THE AUTOBIOGRAPHY OF SIMON LAKE, as told to Herbert Corey. 303 pages, plates, 13 × 20 cms. New York, D. Appleton-Century Co., Inc., 1938. Price $3.00.

Herbert Cory certainly undertook a tremendous task in writing the autobiography of Simon Lake. Mr. Lake from early boyhood had a very busy life and his fertile brain was the source of many inventions. The record story is contained in this book which is evidence of the cooperation of both men.

Simon Lake spent his boyhood in New Jersey and obtained some education in the elementary schools in that State and in Philadelphia. He early showed interest in things mechanical in general which was closely followed by an inventive trend. To forward these urgings Mr. Lake attended the Franklin Institute in Philadelphia to study mechanical drawing and thereafter all his ideas were reduced to paper. The Institute has reason to feel proud that it contributed in the way of assisting the inventor of the submarine to realize his ambition. At the age of fourteen the first plans for an undersea craft were developed. The story of the subsequent building of submarines is vividly told. Because Mr. Lake was not a recognized engineer and because he had little and often no money, his path was impeded at almost every turn. Success was very elusive. Even after a craft was constructed and satisfactorily operated the difficulties of interesting others were almost unsurmountable. This part of the story should appeal to every citizen of this country. Mr. Lake, realizing the naval and military advantages of the craft offered his ideas for use of our Government and it is almost unbelievable how he was rejected not only with regard to contracts but quite often in being given a fair hearing. This happened many times, both during peace and war. In the end he was forced to give the benefit of his work to European countries who considered it in such a favorable light that he was paid handsomely. The success of the use of the submarine by Germany during the World War fully shows its value. These crafts used the Lake ideas.

In the end our Government could no longer afford to ignore him. He was called in and some ships were built under his direction. Mr. Lake believes that some of the lives of the crew of the ill-fated S-4 which sank off Block Island could have been saved had the S-4 been equipped with his escape compartments.

The submarine has other uses than military. Salvage of lost cargos is one, cargo carrying is another. Also, it is revealed, Mr. Lake's interests were by no means confined to it. He had many others.

The book is a well written chronicle that provides a mass of interesting information as well as an inspiring story of a very active inventor.

R. H. OPPERMANN.

THE SILVER MAGNET, FIFTY YEARS IN A MEXICAN SILVER MINE. 302 pages, plates, 14 × 21 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $3.00.

The author of this book has led a life under quite unusual circumstances. The book is his story and it is written in a manner of retrospection. When he was but a small child his family moved from a comfortable home environment in Washington, D. C., to a mining camp at Bastopilas in the State of Chihuahua, Mexico. This was in 1880. The author's father represented the owners of the silver mine there and was the active head for a good many years. Under these conditions the family was reared.

The tenor of the story may be likened to that of being comfortably seated in a living room before an open fireplace listening to the recollections of a man who has seen much and done much. The impressions of childhood, adolescence, and manhood are vividly portrayed. The many varied and interesting customs of the Mexican people, the terrain of the country, the difficulties and pleasures of life, the mining operations, and many other subjects are explained in such a friendly and interesting manner that the reader actually lives with the author over this long period of years. While the general trend is chronological, the story is not strictly so, which makes it more natural and appealing.

There are many parts to the book which should be especially interesting to different readers. Those whose interests lean to adventure will be satisfied, as those who desire descriptive matter of a strange country or strange people. Probably all readers have some interest in a first-hand opinion of an observer on the ground regarding the government of Mexico under Porfirio Diaz and the results of activities of Pancho Villa. At the end of the book too, general interest should be maintained by the author's experiences in Tampico in 1914. The book should rank high for its feature of being informative and entertaining.

R. H. OPPERMANN.

ELECTRIC POWER CIRCUITS, THEORY AND APPLICATION. Volume II, Power System Stability. 698 pages, illustrations, 15 × 23 cms. New York, McGraw-Hill Book Company, Inc., 1938. Price $7.00.

It is readily appreciated that the management and the engineering of the huge present-day electric power systems involve large and difficult problems. It is a division of electric power engineering that requires close and constant scrutiny, and scientific advances in the art must be given careful consideration as to their applicability. Every detail must be looked into before a system or an addition to a system is constructed. So great has been the progress in knowledge and its

application in transmission lines that every few years, it seems greater and greater distances are economically covered with increased stability. With this growth come more difficult problems. One of the major problems which recently has commanded a vast amount of attention and to the solution of which the efforts of the electrical engineering profession have been directed is the problem of system stability.

The book at hand is Volume II of a set on this subject. In the first volume are included the principal aspects of circuit theory and the theory, construction, and general use of the circle diagrams and charts for the solution of power circuit problems. In the present book these theories and tools are specifically applied to the analytical and graphical analysis of stability problems met with in large power systems. In general both solutions of each problem are given. In cases where the problem does not yield readily to more than one kind of solution, or in cases where no alternative solution is yet worked out, although its establishment may be fully possible, only one method is given, either analytical or graphical.

The treatment starts with a perspective of the stability problem, then steady-state power limits and stability of simple and compound systems are taken up. Later there is discussed transient stability, analysis of loaded and unloaded exciters, action of voltage regulators and excitation systems, inertia and grounding, and damper windings and their effect. The very material aid which may be had from the use of a network analyzer in connection with solutions of steady-state as well as transient stability problems is emphasized in many instances.

The book is modern in every respect. The approach used is one which should result in a definite and lasting impression and the discussion is in a logical, matter-of-fact way. For an up-to-date practical treatment of this subject, those who have the necessary prerequisites will do well to examine this book.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 628, Aerodynamic Characteristics of a Large Number of Airfoils Tested in the Variable-Density Wind Tunnel, by Robert M. Pinkerton and Harry Greenberg. 49 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 15 cents.

The aerodynamic characteristics of a large number of miscellaneous airfoils tested in the variable-density tunnel have been reduced to a comparable form and are published in this report for convenient reference. Plots of the standard characteristics are given for each airfoil and, in addition, the important characteristics are given in tabular form. Included also is a tabulation of important characteristics for the related airfoils reported in N.A.C.A. Report No. 460.

This report, in conjunction with N.A.C.A. Report No. 610, makes available in comparable and convenient form the aerodynamic data for airfoils tested in the variable-density tunnel since January 1, 1931.

Report No. 631, Airfoil Section Characteristics as Applied to the Prediction of Air Forces and their Distribution on Wings, by Eastman N. Jacobs and R. V. Rhode. 30 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

The results of previous reports dealing with airfoil section characteristics and span load distribution data are coordinated into a method for determining

the air forces and their distribution on airplane wings. Formulas are given from which the resultant force distribution may be combined to find the wing aerodynamic center and pitching moment. The force distribution may also be resolved to determine the distribution of chord and beam components. The forces are resolved in such a manner that it is unnecessary to take the induced drag into account.

An illustration of the method is given for a monoplane and a biplane for the conditions of steady flight and a sharp-edge gust. The force determination is completed by outlining a procedure for finding the distribution of load along the chord of airfoil sections.

Report No. 632, The Crinkling Strength and the Bending Strength of Round Aircraft Tubing, by William R. Osgood. 15 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

The upper limit of the column strength of structural members composed of thin material is the maximum axial stress such members can carry when short enough to fail locally, by crinkling. This stress is a function of the mechanical properties of the material and of the geometrical shape of the cross section. The bending strength, as measured by the modulus of rupture, of structural members is also a function of these same variables. Tests were made of round tubes of chromium-molybdenum steel and of duralumin to determine the crinkling strengths and the bending strengths in terms of the specified yield strength and the ratio of diameter to thickness. Empirical formulas are given relating these quantities.

Report No. 633, Pressure Distribution over an N.A.C.A. 23012 Airfoil with a Slotted and a Plain Flap, by Carl J. Wenzinger and James B. Delano. 32 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 15 cents.

Pressure-distribution tests of an N.A.C.A. 23012 airfoil equipped with a slotted flap and with a plain flap were made in the 7- by 10-foot wind tunnel. A test installation was used in which the 7-foot-span airfoil was mounted vertically between the upper and lower sides of the closed test section so that two-dimensional flow was approximated. The pressures were measured on the upper and lower surfaces at one chord section both on the main airfoil and on the flaps for several different flap deflections and at several angles of attack.

The data are presented in the form of pressure-distribution diagrams and as graphs of calculated section coefficients for the airfoil-and-flap combinations and also for the flaps alone. The results are useful for application to rib and flap structural design; in addition, the plain-flap data furnish considerable information applicable to the structural design of plain ailerons.

ELECTROMAGNETICS, A DISCUSSION OF FUNDAMENTALS, by Alfred O'Rahilly. 884 pages, illustrations, 14 × 22 cms. New York, Longmans, Green and Co., 1938. Price $12.50.

The theory of electrical phenomena has been investigated and discussed over and over again with the result that today many controversial points exist and the

final solution remains elusive, although it cannot be doubted that valuable contributions in thought have aided very materially toward a concrete definiteness.

"Electromagnetics" is a book that fulfills; first, the purpose of restating the current theory, what it is, and what it rests on; second, a review of existing knowledge and the work which led to it; third, a constructive criticism without regard for authority. The main theses are; that it is maintained that Maxwell's views, which were logically stated by Helmholtz and Duhem, are really off the line of development, the ideas of Gauss and Weber are vindicated, and the proposals of Lorenz and Riemann are claimed to supersede Maxwell's displacement- current; the synthetic statement of the accepted "classical" electromagnetic theory is shown to be the formula published in 1898 by Lienard; the universally ignored alternative formula proposed by Ritz in 1908 is equally and even more successful and even though his theory is not accepted, it has at least the merit of proving the unsoundness of most of the arguments adduced in favor of the prevalent view; Einstein's use of Voigt's transformation, generally known as the special theory of relativity, is subjected to fundamental criticisms as regards electromagnetics; an elementary but radical exposition of units and 'dimensions' is treated in a simple but revolutionary manner.

Undoubtedly there is much to which readers of this book will not agree and it is quite possible that most reconstruction of this sort will meet with opposition. But regardless of this, the work cannot help but cause a great deal of reflection and thought in the minds of serious students of electromagnetics.

R. H. OPPERMANN.

DER INDIKATOR, von Prof. K. J. DeJuhasz und Dr.-Ing. J. Geiger. 293 pages, illustrations, 16 × 24 cms. Berlin, Julius Springer, 1938. Price 28.80 R.M.

Probably every engineer, regardless of his specialization, remembers from his training period, the steam engine indicator. Those who are more familiar with engines know that the indicator was a means through which much improvement was made in the reciprocating engine and its influence was felt in gas and oil engines of the old slow speed types to the new high speed economical motor. In the past 20 years there has been much development in the indicator so that today there are several fundamental classes of indicators of high standard of performance. As a result of this development the engineer is often called upon to work with an indicator with which he has little experience or knowledge. That is the aim of this book, to impart a working knowledge of the modern instrument in all of its fundamental theoretical bases.

The work begins with a brief history of the indicator, its inception and improvement by various workers as time went on. Following this the mechanical ndicator is described, its parts, assembly, and method of operation. Indicators for high speed motors such as the microindicators of Mader, Collins, Schmitz and Pabst are next taken up with quite some space devoted to the optical or reflector type instrument. Under electrical indicators the oscillograph is discussed and methods of indication involving variable resistance, potential, capacity and inductance. Point indicators, indicators of averages, inspection and adjustment of indicators, faulty diagrams, and dynamical theory of indicators are all thoroughly explained. At the end of the book are arranged literature references on every phase of the subject.

The book is well illustrated with drawings, diagrams and photographs and the treatment is broad in scope and thorough. It should have great value to anyone whose interests lie in this direction.

R. H. OPPERMANN.

THE MAGIC WAND OF SCIENCE, by Eugene W. Nelson. 213 pages, plates, illustrations, 13 × 19 cms. New York, E. P. Dutton & Company, Inc., 1938. Price $2.00.

This book belongs to the class of books that aim to interpret to the layman the wonders of the scientific world which play an important part in everyday life. This class may be subdivided into the elementary or those of an introductory nature and those which appeal to readers who are more versed in some of the knowledge of science. The present book belongs to the former. It is broken into thirty chapters each devoted to a separate and distinct topic. As there are in all 213 pages including quite a few illustrations, each chapter is necessarily brief.

A few of the subjects treated are enzymes and their actions and results in the human body, the wonderland of plastics which is probably the fastest growing chemical industry today, and cosmic rays. In the latter the theory of Dr. Swann of The Franklin Institute is cited among those outstanding of the many theories advanced. Generally the author has done well in his translation of the scientific to everyday language in the space available. It must be realized that to do this adequately is exceedingly difficult. Non-scientific readers will obtain greater appreciation of the work of science by reading this book.

R. H. OPPERMANN.

ALTERNATING CURRENT CIRCUITS, by Russell M. Kerchner and George F. Corcoran. 510 pages, illustrations, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.75.

The fundamentals of any engineering subject must be thoroughly and permanently absorbed by every student aspiring to successful practice. It is therefore of very great importance that a test on fundamentals be designed with much care and so constructed as to make impressionable the subject matter with the least possible effort. Many courses claim short cuts to the desired end but it is a fact that thoroughness in preparation results in thoroughness of accomplishment. The book at hand is a text on the fundamentals of alternating current circuits, a subject upon which, it might be said the greater part of electric power engineering rests. As such it is exposed to the rigid requirements necessary in a basic work.

It begins with a short chapter on general concepts and definitions which is a means of directing attention into a path which leads up to the subject. From here the treatment goes into instantaneous current and power, and effective current and voltage. Next, vector algebra as applied to A.C. circuit analysis is explained clearly. With this as a tool the treatment progresses through a logical sequence of topics. Sinusoidal single-phase circuit analysis, non-sinusoidal waves, coupled circuits, polyphase circuits, are all thoroughly explained. Transmission lines in-so-far as their fundamental electrical characteristics are considered and calculations with respect to these are treated upon. Likewise the separation of waves of different frequencies as in a filter is discussed and following this a groundwork on

fundamentals of symmetrical components prepares for power system short circuit calculations. The last chapter treats on transient circuit or machine conditions.

The book is well planned and sets forth the subject very nicely. More than the first half of it is built up from the simple to the more complex in logical and orderly sequence. The latter part is mostly made up of extensions and applications of the principles studied earlier so that sections of this may be omitted without affecting preparation for studying succeeding chapters.

The problems at the end of each chapter reveal a knowledge of what is necessary to make the subject impressionable as well as a knowledge of the practical needs of the practicing engineer. The book, is well illustrated with diagrams and photographs of oscillograms. There is a subject index in the back. It fully meets the requirements of an introductory text.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Atomic Structure, by Leonard B. Loeb. 445 pages, illustrations, 15 × 24 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.50.

A Dual Theory of Conduction in Metals, by Edwin Herbert Hall. 170 pages, illustrations, 14 × 21 cms. Cambridge, The Murray Printing Company, 1938. Price $2.00.

Some Notes on Least Squares, by W. Edwards Deming. 181 pages, illustrations, 20 × 26 cms. Washington, The Department of Agriculture, 1938. Price $1.50.

A Course of Study in Chemical Principles, by Arthur A. Noyes and Miles S. Sherrill. Second Edition, Rewritten. 554 pages, illustrations, tables, 15 × 22 cms. New York, The Macmillan Company, 1938. Price $5.00.

A Manual of Experiments, to accompany A First Course in Physics for Colleges, Revised Edition, by Robert Andrews Millikan, Henry Gordon Gale and Charles William Edwards. 221 pages, illustrations, tables, 20 × 26 cms. Boston, Ginn and Company, 1938. Price $1.10.

Chemical Engineering Catalog, 1938, Twenty-Third Annual Edition. The Process Industries' Own Catalog. 1034 pages, illustrations, 20 × 28 cms. New York, Reinhold Publishing Corporation.

Blätter für Geschichte der Technik. Viertes Heft, Schriftleitung: Dr. Ing. L. Erhard. 80 pages, illustrations, 17 × 25 cms. Wien, Julius Springer, 1938. Price 4 R.M.

United States Department of the Interior, Bureau of Mines. Minerals Yearbook, 1938. Compiled under the supervision of H. Herbert Hughes. 1339 pages, illustrations, tables, 15 × 23 cms. Washington, Superintendent of Documents, 1938. Price $2.00.

Dominion Bureau of Statistics, General Statistics Branch, Department of Trade and Commerce. The Canada Year Book, 1938. 1141 pages, illustrations, tables, 16 × 23 cms. Ottawa, King's Printer, 1938. Price $1.50.

Standards on Radio Receivers, 1938. 58 pages, illustrations, 15 × 23 cms. New York, The Institute of Radio Engineers, Inc., 1938. Price 50 cents.

Standards on Electronics, 1938. 59 pages, illustrations, 15 × 23 cms. New York, The Institute of Radio Engineers, Inc., 1938. Price 50 cents.

Canada, Department of Trade and Commerce, Dominion Bureau of Statistics, Mining, Metallurgical and Chemical Branch. Annual Report on the Mineral Production of Canada, during the calendar year 1936. 309 pages, tables, 16 × 23 cms. Ottawa, King's Printer, 1938. Price 40 cents.

National Advisory Committee for Aeronautics. Technical Notes: No. 663, The Effects of Partial-Span Plain Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered Clark Y Wing, by R. O. House. 13 pages, illustrations. No. 664, Free-Spinning Wind-Tunnel Tests on a Low-Wing Monoplane with Systematic Changes in Wings and Tails. III. Mass Distributed Along the Wings, by Oscar Seidman and A. I. Neihouse. 29 pages, illustrations. No. 665, Tests of N-85, and N-87 Airfoil Sections in the 11-Inch High-Speed Wind Tunnel, by John Stack and W. F. Lindsey. 11 pages, illustrations. No. 666, Longitudinal Stability in Relation to the Use of an Automatic Pilot, by Alexander Klemin, Perry A. Pepper, and Howard A. Wittner. 63 pages, illustrations. No. 667, Operational Treatment of the Nonuniform-Lift Theory in Airplane Dynamics, by Robert T. Jones. 11 pages, illustrations. No. 668, Hydrodynamic and Aerodynamic Tests of Models of Flying-Boat Hulls Designed for Low Aerodynamic Drag N.A.C.A. Models 74, 74-A, and 75, by Starr Truscott, J. B. Parkinson, John W. Ebert, Jr., and E. Floyed Valentine. 56 pages, illustrations. No. 670, N.A.C.A. Stall-Warning Indicator, by F. L. Thompson. 14 pages, illustrations. 7 pamphlets, 20 × 26 cms. Washington, Committee, 1938.

Bell Telephone System, Monographs: B-1078, Certain Guided Waves in Slightly Noncircular Tubes, by S. A. Schelkunoff. 10 pages, illustrations. B-1079, Diffraction Produced by Obstacles and Plates, by G. G. Muller, R. Black and T. E. Davis. 18 pages, illustrations. B-1080, Spectrochemical Analysis in Communication Research, by Beverly L. Clarke and A. E. Ruehle. 12 pages, illustrations. B-1081, Magnetic Shielding of Transformers at Audio Frequencies, by W. G. Gustafson. 22 pages, illustrations. B-1083, Instruments for the New Telephone Sets, by W. C. Jones. 20 pages, illustrations. B-1084, An Optical Harmonic Analyzer, by H. C. Montgomery. 10 pages, illustrations. Appendix to Index of Monographs, Index by Number-Continued, July, 1938. 7 pages. 7 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1938.

CURRENT TOPICS

General Reactions of 274 Office Workers to Summer Cooling and Air Conditioning.—F. C. HOUGHTEN, A. B. NEWTON, R. W. QUALLY, and E. WITKOWSKI. (*Heating, Piping and Air Conditioning*, Vol. 10, No. 8.) This is the result of a questionnaire as part of research sponsored by an Amer. Soc. of Heating and Ventilating Engrs.' Committee, conducted under the supervision of the Technical Advisory Committee on Sensations of Comfort. The office workers were employed in air conditioned offices in Minneapolis during the summer of 1937. Answers to the questionnaire show a considerable percentage of general satisfaction in experiences resulting from air conditioning. Better than 35 per cent. were frank in stating that they felt too warm for a while after leaving the air conditioned space. An equal percentage showed an entire indifference to or a lack of this hot reaction. A little over 70 per cent. indicated clearly that their unpleasant reactions to hot nights or unpleasant reactions to a spell of hot weather were lessened by spending the working part of the day in the summer-cooled air conditioned space. Sixty-six per cent. in one way or another indicated definite positive reaction. These reported better feeling, more pep, greater efficiency, greater comfort, and pleasure. It is felt that the questionnaire showed a general satisfaction to air conditioning and a lack of severity and importance of the hot reaction upon leaving the air conditioned space. Similar studies are being planned for other sections of the country. The importance of this type of analysis is just being recognized and should be made an important part of future investigations.

R. H. O.

Air Conditioning Fruit Cars With Diesels.—(*Heating and Ventilating*, Vol. 35, No. 8.) Few people realize that fruit, vegetable and meat-carrying freight cars were users of air conditioning long before the first passenger car. Refrigerated cars for perishable goods have been in service for over a third of a century—and a crude form of air conditioning was what made possible the movement of perishables over long distances. Equally as important as the maintenance of low temperatures during transit is the problem of precooling the car before it is started on its journey. This has been the subject of research in recent years which has resulted in what may revolutionize previous methods. A diesel-powered refrigera-

tion plant consisting of a Cummins diesel, compressor, condenser, brine tanks, and circulating pumps, is mounted on a structural steel base about the size of an average truck trailer, which, when in service, is transported to the railroad siding where the cars are to be loaded. The balance of the equipment consists of six small structures in which are located the heat exchange equipment and circulating fans. Six produce cars may be cooled at one time. Canvas shrouds that completely enclose the car doors extend from the cooling structures to the sides of the cars. These cooling units are so built that the air in the car is drawn through the cooling medium and returned to the car once every two seconds. At the same time the air is cooled it is also washed and humidified. A car loaded with grapes or plums can be brought down to about 39° F. in six hours—and strawberries in about two hours. This compares to about 72 hours and 36 hours respectively when ice alone is used. Another factor of tremendous importance is that temperatures on various tiers of fruit at various places in the cars, and even in the centers of the crates, are fairly uniform.

R. H. O.

Pipe Fabricated by Continuous Process.—(*Chemical and Metallurgical Engineering*, Vol. 45, No. 8.) A new method developed by the engineering department of Spang Chalfant, Inc. is adaptable to low carbon and copper steel pipe in sizes from ½ to 3 inches inside diameter. It consists of flash welding the end of the skelp on one reel to the beginning of the next reel. While the weld is white hot it passes through the trimmer where it is dressed off leaving smooth surfaces top and bottom. The continuous skelp passes through a gas-fired 143 ft. heating furnace at uniform rate of speed. Heat resistant alloy rolls and water-cooled skids prevent the skelp contacting the furnace lining and becoming contaminated by the slag during its journey. As the skelp leaves the furnace the two edges are brought together by forming rolls and welded. The continuous pipe is cut into 20 ft. lengths, the scale removed, ends threaded, etc. Each length of pipe is inspected and tested. The joints are said to result in a stronger, more durable pipe, in addition to being free of ridges inside as well as outside, which are caused by ordinary methods of welding and which interfere with the flow of liquids and gases through the pipe.

R. H. O.